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EFFECTS OF EXPLOSIONS IN SHALLOW WATER

REPORT NO. 5

CRATERING EFFECTS IN SAND, SURFACE WAVES, AND AIR BLAST MEASUREMENTS FOR A SCALED WATER DEPTH OF 30 FT.

PREPARED FOR

ARMED FORCES SPECIAL WEAPONS PROJECT
DEPARTMENT OF DEFENSE

AND

THE CHIEF OF ENGINEERS
DEPARTMENT OF THE ARMY

WATERWAYS EXPERIMENT STATION
VICKSBURG, MISSISSIPPI

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PREFACE

This report is the fifth in a series to be published on the study of the Effects of Explosions in Shallow Water being conducted for the Armed Forces Special Weapons Project, Department of Defense, and the Office, Chief of Engineers, Department of the Army, by the Waterways Experiment Station. The reports are published intermittently during the course of the study to describe a completed phase or series of tests. A comprehensive report to be prepared at the conclusion of the study will attempt to correlate and summarize in more general form the detailed results presented in these reports. This report describes the cratering effects in sand, water surface waves, and air-blast measurements resulting from the scaled explosion of a 20-kiloton bomb in a 30-ft water depth.

A list of the reports in preparation or published to date is printed on the inside of the front cover of each report for the information of the reader.

Symbols and the less familiar abbreviations used throughout this report are defined on pages 29 and 30.

EFFECTS OF EXPLOSIONS IN SHALLOW WATER

REPORT NO. 5

Cratering Effects in Sand, Surface Waves, and Air-Blast Measurements for a Scaled Water Depth of 30 Ft

Introduction

1. Reported herein are the results of a series of small-scale tests to determine the cratering effects in sand and the magnitude of surface waves and air blast caused by an explosion of 20,000 tons of TNT in a water depth of 30 ft. Tests with charge weights up to 32 lbs were conducted at the Waterways Experiment Station. Charge weights in excess of 32 lbs were detonated in an old channel of the Mississippi River about 10 miles south of Vicksburg, Mississippi. A description of the WES test site, similitude considerations, and testing procedure are contained in Report No. 1; however, a brief presentation of this information is repeated herein for the convenience of the reader.

Description of Test Sites

2. Tests with charge weight of 32 lbs, or less, were conducted on the Waterways Experiment Station reservation in a keyhole-shaped basin. The basin was excavated to an approximate depth of 5 ft in undisturbed loess soil. Water supply and drainage for the test basin, and shelter for instrumentation equipment are as shown on plate 1.

A pit approximately 60 ft long, 20 ft wide and 5 ft deep was excavated in the circular part of the test basin, and was filled with sand to provide the desired bottom material. Tests using charge weights up to 2048 lbs were conducted about 10 miles south of Vicksburg, Mississippi, in an old channel of the Mississippi River near Diamond Cut-Off. The deep deposits of sand in the form of long, flat bars along the old river bed provided an excellent test site which was about three miles distant from the nearest residents.

Similitude Considerations

3. The principle of similarity, generally accepted for explosive work with scaled charges, states that if the linear size of a charge be changed by some factor k, the pressure condition will be unchanged if the scales of distance and time are changed by the same factor. That is, pressure conditions or the magnitudes of other physical phenomena associated with an explosion can be written as functions of distance and time for any explosion once they are known for a specific explosion, by scaling all distances and times in accordance with the ratio of the linear sizes of the two charges. The cube root of the charge weight ($W^{1/3}$) is used as a convenient measurement of linear size. Although the validity of the above principle for scaling the various phenomena involved in the problem at hand was uncertain, it was assumed correct until test results either confirmed the principle or permitted a more accurate determination of scaling laws.

4. The depth of water used in the tests was therefore based on the ratio, $D/W^{1/3}$, which for the prototype depth of 30 ft and the charge weight of 20,000 tons is 0.088. Actual water depths used in the tests were 0.07, 0.14, 0.22, 0.28, 0.56, and 1.12 ft for charge weights of 0.5, 4, 16, 32, 256, and 2048 lbs, respectively.

Test Conditions and Procedures

5. The study of explosions in shallow water involves the determination of effects of exploding 20,000 tons of TNT in water depths of 30, 60, 100, and 200 ft on (a) cratering in various soils, (b) air blast, (c) shock waves in water and earth, and (d) surface water waves. Initial tests were concerned with cratering effects in loess soil and measurements of surface water waves. Results of these tests for scaled water depths of 200 ft and 30 ft are contained in Reports Nos. 1, 2, and 4*. The tests reported upon herein were concerned with cratering effects in sand and measurements of air blast and surface water waves for a scaled water depth of 30 ft.

6. The test charge weights, except the 16-lb charge, were so selected that the magnitudes of all physical phenomena would be reduced or increased by a factor of 2. That is, the same pressures would exist for the 0.5-lb charge (1/8 the weight) as for the 4-lb charge at half the distance and time; the same pressure would exist for the 32-lb charge

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* See list of reports on inside of front cover.

(8 times the weight) as for the 4-lb charge at twice the distance and time. The 32-lb charge was the largest that could be detonated on the WES reservation because of the location of the test basin with respect to residential areas. Charges of 0.5, 4, 16, and 32 lbs were made up from standard Corps of Engineers 0.5-lb and 1-lb TNT demolition blocks arranged where practical to maintain approximate geometric similitude of charge dimensions (plate 2). Spherically-shaped charges of cast TNT for weights of 0.5, 4, 32 and 256 lbs were used when air-blast measurements were made. Diameters of the spheres were 0.215, 0.432, 0.863, and 1.725 ft for the 0.5, 4, 32, and 256-lb charges, respectively. The charge of 2048 lbs was built up in the shape of a cube with 100-lb blocks of cast TNT and Corps of Engineers 1-lb demolition blocks.

7. Tests in the WES basin included charges fired at scaled depths of 45 and 90 ft below the bottom, at the bottom, at the water surface, and at 0.5D above the water surface as shown on plate 2. The 32-lb charge was not fired in the latter two positions because of complaints from nearby residents. The 16-lb charge was used instead to extend the range of data in these charge positions. The center of gravity of the charge was used in all tests as the reference for charge position. The built-up charges were placed with the long side in a vertical position. Three to five identical charges were fired in each position to insure that test data were reliable.

Waterways Experiment Station test site

8. Testing procedures for tests conducted on the WES reservation

were similar to those described in Report No. 1. The test basin was graded level in the test area to insure that bottom variations did not interfere with wave formations in the shallow water depths. Charge sites were fixed, prior to flooding the basin, by placing wood stakes at safe distances on a rectangular grid. Lengths of steel pipe were driven into the bottom to locate and support wave rods and air-blast gages. Wave rods were spaced on a line radiating from the charge position at scaled distances of R/D = 60, 100, and 200, where R is the actual distance in ft from the charge and D is the actual depth of water in feet. Air-blast gages were mounted one foot above the water surface on a similar line at reduced distances (λ)* of 6, 10, 15, and 20. Air blast and water shock were measured with tourmaline piezoelectric gages and recorded on 10-in. strips of 35-mm film with rotating drum cameras mounted on Dumont Type 304H cathode-ray oscilloscopes. Air-blast gages were 7/8, 1-1/8, and 1-5/8 in. in diameter and water-shock gages were 1/4 in. in diameter. Only the air-blast measurements are reported herein, inasmuch as water-shock records were not obtained in the shallow water depth. Occasionally, when a readable record was obtained from the channels used to record water shock, analysis showed it to be caused by air-blast pressure.

9. The test basin was flooded to the proper depth after the charge locations were fixed and air-blast gages were mounted. Wave rods were

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* $\lambda = R/W^{1/3}$.

calibrated and attached to their supports just prior to the placing of the charge. Electrical cables connected the wave rods and air-blast gages to recording equipment in the instrument building. It was necessary to support blast-gage cables above the water surface to eliminate "cable signal" produced by either water or earth shock. The test area was then cleared of personnel and the charge was placed in the basin at the desired position and prepared for detonation. The charge was detonated from the instrument shelter by means of an electrical circuit which was synchronized with control circuits of the air-blast recording equipment.* Surface waves and air-blast measurements were recorded during the detonation process. Still and motion pictures of a representative number of shots were made also of the surface phenomena during the explosion. The basin was drained after each test shot to obtain photographs and complete measurements of the crater.

10. Craters less than 10 ft (model) in width were measured by means of a square framework centered over the charge location, which provided both horizontal and vertical controls for crater soundings and horizontal dimensions. An aluminum rail supported horizontally was substituted for the framework in measuring larger craters. At least two profiles through representative cross sections of the crater were obtained.

Field test site

11. Procedures for conducting tests with the large charges in the

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* Details of instrumentation for the project will be the subject of a later report.

old river channel south of Vicksburg were generally the same as those followed at the Waterways Experiment Station test basin. Instrumentation equipment and portable generators for electrical power supply were housed on a 20-ft by 48-ft steel barge, anchored from 800 to 1100 ft from the charge location. A minor modification of air-blast equipment was made in that cathode followers were added in the cable lines about 200 ft from the tourmaline gages to overcome the loss of signal strength due to the additional cable length required to reach the barge.

12. Charge locations were selected to provide the proper water depth and a fairly level bottom extending a distance from the charge sufficient to place gages and wave rods. The locations and spacings of these instruments were fixed by the scaled distances used at the WES test basin and described in paragraph 8.

13. Tests at the field site included (a) 32-lb charges fired at scaled depths of 90 and 45 ft below the bottom, at the bottom, at the water surface, and at 0.5D above the water surface; (b) 256-lb charges fired at scaled depths of 90 and 45 ft below the bottom and at the bottom; and (c) a 2048-lb charge fired at the bottom. The center of gravity of the charge was used in all tests as the reference for charge position. At least two identical charges were fired in each position with the exception of the 2048-lb weight for which one shot was made.

14. A small darkroom was provided on the instrument barge for developing the photographic records of test data and for loading the drum cameras. Thus the records for each shot were available shortly after

the blast for inspection to determine the necessity for repeating the test before the barge was moved.

15. Crater measurements were made by holding a 100-ft metallic tape across the center of the crater and taking level-rod readings at 6-in. intervals along the tape. At least two representative profiles of each crater were obtained in this manner. Some difficulty was encountered in sounding the craters obtained from the field shots in that the craters could not be pumped dry.

Test Results -- Cratering

Test data

16. Tables 1-4 present a summary of data obtained from cratering tests in the WES basin using the 0.5-, 4-, 16-, and 32-lb charges. Two complete profiles were taken through representative sections of each crater and the data plotted as an average half-crater profile. Crater dimensions listed in the tables were obtained from these plots. Reduced crater dimensions, defined as the dimension divided by the cube root of the charge weight, are also listed in the tables. The relatively low values of the standard deviation of the mean indicate the data to be consistent for comparable charge weights and positions. A number of explosions produced a dry crater with lips above the water surface. Although the crater lips collapsed within a few seconds and the crater filled with water, efforts were made to measure the crater depth (d_1) before collapse of the lips. Crater depths are listed in two columns, d and d_1, where

the latter represents the depth before collapse of the crater lip. It was not possible to obtain this measurement in all tests because of insufficient time between the explosion and lip collapse.

17. Listed in table 5 are two separate values for K and n(where K and n relate to the empirical equation, $P = KW^n$) for the various charge positions as determined by: first, averaging the reduced crater dimensions as listed in tables 1-4; and second, by determining the empirical equation best fitting the experimental data by the method of least squares. Table 6 presents the results of both WES basin and field tests for a charge positioned at the bottom (Z = -1.0D).

18. Photographs 1-5 present views of typical craters for the various charge positions with the 16-lb charge. Photographs on plate 3 show in sequence the erosion or collapse of the crater lip at various times after the detonation of a 32-lb charge positioned at Z = -4.0D. The crater formed by a 256-lb charge (field test) positioned at Z = -1.0D is shown in photograph 6.

19. Plates 4-11 show half-crater profiles, representing the average of all data for each charge weight and position. Each plotted point represents the average crater depth as obtained from four separate soundings at equal radial distances from the charge. The half profile shown by the solid line represents the crater shape after the lip collapse,while the dashed line presents the approximate profile before the lip failed. Shown also on the plates in tabular form are the six crater measurements of major concern: depth, width, lip height, lip width, area, and volume.

20. Plates 12-22 show the average values of various crater dimensions plotted as a function of charge weight. Plates 12 and 13 show the effect of charge weight on crater depth for the various charge positions both before and after erosion of the crater lip. Values of the plotted points for each charge weight and position were taken from mean values listed in tables 1-4.

21. Plate 12 shows the effect of charge weight on crater depth prior to the collapse of the crater lip. Insufficient time between detonation and lip collapse made it impossible to obtain the data for charges positioned at and above the water surface. The maximum depth of crater for each charge weight occurred when the charge was placed at $Z = -4.0D$. With the charge at this position the crater was approximately one-and-a-half times the depth obtained with the charge at the bottom. Exponents of the charge weight (W), as shown in the equations of the various lines drawn through the plotted points, indicate a fair agreement with the cube root scaling law. Plate 13 presents a plot of crater depth versus charge weight after lip collapse, and when compared with plate 12 indicates the effect of lip collapse on the ultimate depth of crater. The ratio of crater depth prior to lip collapse to the crater depth after lip washout is approximately 1.8 for all comparable charge weights and positions. The collapse of the crater lip thus causes a significant departure from the cube root scaling law, as shown by the exponents of charge weight in the empirical equations developed for each charge position.

22. Plate 14 shows the effect of charge weight on crater width. Maximum crater widths were produced by charges positioned at Z = -4.0D. As the charge location approached the water surface the width decreased significantly for comparable charge weights. Little difference in crater width was noted for comparable charges fired at and above the water surface. The average value of charge weight exponent for all charge positions is 0.335 indicating a close agreement with the assumed scaling law.

23. Plate 15 shows the effect of charge weight on crater-lip height for the various charge positions. The empirical equations shown thereon indicate the lip height to vary approximately as the four-tenths power of the charge weight with the exception of the condition where the charge was detonated above the surface (Z = 0.5D). The latter plot is considerably affected by the erratic results obtained with the 1/2- and 4-lb charges. The plots indicate that the height of the crater lip increased progressively as the charge was lowered.

24. Plates 16 and 17 show area and volume of crater versus charge weight for the various charge positions. Average of all exponents of the charge weight as shown in the empirical equations indicates the crater area to vary approximately as a function of the six-tenths power of the charge weight, and the crater volume to vary directly as a function of the first power of the charge weight. These data show almost exact agreement with the cube-root-of-charge-weight scaling law.

25. Plates 18-22 show cratering results of both WES basin and field tests for the various charge weights where each charge was positioned at

the bottom (Z = -1.0D). Crater measurements prior to the lip washout were not possible for the field shots; therefore, these data refer only to the crater dimensions after the lip collapse.

26. Plate 18 shows the effect of charge weight on crater depth. Good agreement between data obtained at both test sites is indicated by the linear relationship of the plotted points along the straight line. The combination of test results from the two test sites shows a better agreement with the $W^{1/3}$ scaling law as evidenced by a comparison of the empirical equation for charges fired at the bottom, shown on plates 13 and 18. The collapse of the lip and subsequent filling of the crater, as mentioned previously, had appreciable effect on the scaling relationships and probably accounts for the departure from the $W^{1/3}$ scaling law.

27. Plate 19 shows a plot of crater width versus charge weight. Since the width of crater was not noticeably affected by the lip collapse outside the immediate area of erosion, the equation for these data compares very favorably with the equation for the WES basin data plotted on plate 14 (charge positioned at Z = -1.0D). Summarizing the results obtained for all charge weights and assuming the cube root of charge weight law to be valid, the width of crater for a charge positioned at the bottom may be defined by the empirical equation, $w = 3.59W^{1/3}$.

28. Significant crater lips were formed for every charge weight and position tested. Although plate 11 shows the lip heights for the 256- and 2048-lb charges to be quite small, as measured after erosion of the lips, prominent lips were in evidence immediately after the charges were

fired. The lip height for the 256-lb shot at Z = -1.0D was scaled from photographs to be 1.7 ft. The lip height for the 2048-lb shot immediately after firing was estimated to be approximately 2.5 ft. Such heights were not in evidence at the time the two craters were sounded because of the collapse of the lip and the settling characteristics of the river sand. The height of crater lip for charges positioned at Z = -1.0D and for all charge weights tested further indicates that the phenomenon varies approximately as a function of the four-tenths power of W, as shown on plate 20.

29. Plates 21 and 22 show plots of area and volume of crater versus charge weight. Exponents of the charge weight as shown in the empirical equations for these parameters are in close agreement with the cube root scaling law. Close agreement between results of tests in the field and in the WES test basin was obtained also.

30. Plate 23 shows plots of the various reduced crater measurements versus Z/D. The equations permit calculation of the various crater parameters for a charge fired at any position within the range tested (Z/D = -4.0 to Z/D = 0.5). Two plots of reduced crater depth versus Z/D are presented to show the effect of lip subsidence on the ultimate crater depth. The reduced crater width was unaffected by the collapse of the crater lip. The plot of reduced crater-lip height indicates a marked decrease in lip height as the charge position was raised. When the charge was detonated at positions at or above the water surface, the lip height decreased quite rapidly. No attempt has been made to evaluate the effect

of crater lip collapse on the plots of reduced crater area and volume.

31. Plates 24-28 show dimensionless plots of the half-crater profiles for each of the charge positions. In the plot of X/r versus Y/d the ordinate is a ratio of crater depth at any point to the maximum depth at ground zero after lip collapse (Y/d), and the abscissa is a ratio of radial distance from the charge to radius of crater (X/r). Also shown in dimensionless form is the plot of $X/W^{1/3}$ versus $Y/W^{1/3}$, where X is the radial distance from the charge, and Y is the depth of the crater at the distance X. The plots of X/r versus Y/d are fairly consistent throughout the range of positions tested; thus indicating that the craters were similar in shape for the various charge weights and comparable charge positions. Test results of the 0.5-lb charges were omitted from the data describing the average curves in the plots of $X/W^{1/3}$ versus $Y/W^{1/3}$ for all charge positions. The discrepancies indicated by the plotted points give reason to doubt the validity of results obtained with these charges, particularly as concerns crater depth. Previous cratering tests in loess soil, discussed in Report No. 4, also cast doubt on the results obtained with this small charge. Plotted points for other charge weights are within the range of scatter previously experienced in cratering tests.

Discussion of results

32. Results of cratering in sand for the scaled 30-ft water depth indicate that the shallow water had little influence on crater measurements and that, within the limits of the tests, charge position was the

critical factor. The explosions produced initially a dry crater with lips extending above the water surface. At a time which varied from a few seconds to as long as 15 minutes after the detonation, a portion of the lip collapsed (approximately 20 per cent of the periphery) and was washed into the crater. The remaining part of the crater lip was usually left in place (plate 3) although in the field tests a slumping action took place and the height was reduced. The ultimate crater depth was affected appreciably by the material that washed in after the failure of the lip. The effect of lip failure on the scaling of crater depth is shown in table A below.

33. Table A presents the values of "K" and "n" as they pertain to crater depth before and after the collapse of the crater lip for the three charge positions at which these data were obtained.

Table A

Values of "K" and "n" in the Empirical Equation

Crater Depth (d) = KW^n

Charge Position (Z)	d_1, Before Lip Collapse		d, After Lip Collapse	
	K	n	K	n
Z = -1.0D	0.85	0.318	0.55	0.183
Z = -2.5D	1.08	0.301	0.75	0.195
Z = -4.0D	1.27	0.276	1.02	0.157
Average Values of "n"		0.298		0.178

A significant change in scaling is apparent in that the average value of

n was reduced by approximately 60 per cent as a result of the lip failure.

34. Crater lips in sand were quite uniform in shape around the crater periphery before lip failure. The ratio of lip height to water depth (h/D in table B) varied from 1.0 where the charge was placed above the water surface (Z = 0.5D) to 2.1 where the charge was placed below the bottom (Z = -4.0D). Lip heights for all charge positions were of sufficient height to indicate that a 20-kiloton charge detonated in a 30-ft depth on a sand bottom could make navigation hazardous.

35. Table B presents a comparison of the results of cratering tests in sand for the scaled 30- and 200-ft depths.

Table B

Comparison of Cratering Results in Sand for Scaled Water Depths of 30 and 200 Ft

	$D/W^{1/3}$ = 0.585* Scaled Depth(D) = 200 Ft			$D/W^{1/3}$ = 0.088 Scaled Depth(D) = 30 Ft		
Charge Position (Z)	$d/W^{1/3}$	$w/W^{1/3}$	h/D	$d/W^{1/3}$	$w/W^{1/3}$	h/D
Above Surface (Z = 0.5D)	0.04	2.39	0	0.41	2.73	1.0
Surface	0.15	4.14	0	0.40	3.01	1.2
Bottom	0.47	3.93	0.07	0.44	3.41	1.6
Below Bottom**	0.57	4.03	0.07	0.61	3.98	1.9
Below Bottom***	0.64	4.48	0.07	0.79	4.65	2.1

* Data taken from Report No. 3, "Effects of Explosions in Shallow Water," dated July 1952.
** Scaled distance of 45 ft below the bottom.
*** Scaled distance of 90 ft below the bottom.

The reduced crater dimensions compare favorably when the charge was positioned at or below the bottom. Considerable difference in crater depth results, however, when the charge was fired at or above the water surface. Reduced crater widths show comparable values throughout the range of positions tested, indicating that the crater width was somewhat less dependent on water depth and charge position.

36. A comparison of the results of cratering in loess and sand for a scaled water depth of 30 ft is made in table C.

Table C

Comparison of Cratering Results in Sand and Loess
For a Scaled Water Depth of 30 Ft

Charge Position (Z)	Sand			Loess*		
	$d/W^{1/3}$	$w/W^{1/3}$	h/D	$d/W^{1/3}$	$w/W^{1/3}$	h/D
Z = 0.5D	0.41	2.73	1.0	0.81	3.45	0.75
Z = 0	0.40	3.01	1.2	0.84	3.60	0.80
Z = -1.0D	0.44	3.41	1.6	0.88	3.92	1.03
Z = -2.5D	0.61	3.98	1.9	1.05	4.26	1.14
Z = -4.0D	0.79	4.65	2.1	1.19	4.65	0.91

* Data taken from Report No. 4, "Effects of Explosions in Shallow Water," dated August 1952.

The reduced crater dimensions show that the crater depth was approximately twice as great in loess as in sand; the width was slightly greater in loess; and the lip height was significantly greater in sand.

Test Results -- Water (Surface) Waves

General

37. Surface waves were measured at similar scaled distances and in the same manner as described in Report No. 2 for the scaled 30-ft depth. Actual distances of wave rods from the test charges for the various scaled distances were as shown in table D.

Table D

Values of R and D for Test Charges

W, Charge Weight(Lb)	D, Water Depth(Ft)	R, Distance from Charge(Ft) R/D = 60	R/D = 100	R/D = 200
0.5	0.07	4.2	7.0	14.0
4	0.14	8.4	14.0	28.0
16	0.22	13.2	22.0	44.0
32	0.28	16.8	28.0	56.0
256	0.56	33.6	56.0	112.0
2048	1.12	67.2	112.0	224.0

38. This report includes wave data obtained from field tests that involved charge weights of 256 and 2048 lbs. The results obtained with the large charges are presented only on the plates showing the effect of distance from charge and effect of charge weight because of the limited number of positions at which the charges were fired.

Time of arrival

39. Plates 29-32 show the time of arrival of the apparent crest and trough of the first and second waves as recorded on the oscillogram at the various wave rods for each charge weight and position. The plots

indicate that the wave celerity increases with distance from the charge particularly for shots at or near the water surface. Examination of high-speed motion pictures made of the explosion phenomena indicate that the oscillograph recording equipment probably recorded local disturbances caused by fall-out of bed material as well as the wave that moved outward radially from the explosion. Examination of the motion pictures also reveals that a wave was propagated outward radially somewhat later than the fall-out but was not of sufficient magnitude to be readily discernible on all oscillograph records.

40. Celerity computations based on a study of motion-picture records of a 4-lb charge fired on the bottom indicate that the wave moved at an average rate of approximately 2.7 ft/sec after passing the first wave rod, and that the celerity decreased slightly as the distance from the charge increased. This compares with the theoretical celerity of a gravity wave in shallow water (2.1 ft/sec for these conditions) in the same manner as experimental and theoretical celerities compared for the tests in the scaled 200-ft water depth (Report No. 3).

Effect of charge position

41. Plates 33-40 show the effects of charge position on the height of the first and second waves at three scaled distances from the explosion. It will be noted that, where applicable, test results obtained with loess soil as bottom material and previously presented in Report No. 2 have been added to these plots to provide data for additional charge positions. The latter data have been corrected to refer charge position

to the charge center of gravity. These plots show that in most instances the height of both the first and second waves increased slightly as the charge varied either above or below the 0.5D (half depth above surface) position, with the greatest increases occurring at positions below this point. This agrees with the belief that the recorded waves or disturbances were caused in part by the throw-out of bed material which definitely increased in quantity as the charge was fired at lower positions.

Effect of distance from charge

42. Plates 41-46 show the effect of distance from the charge on crest height above still water (a_{+1}) and crest height plus trough depth ($a_{+1} + a_{-1}$) for the first wave. Since the points plotted on log-log coordinates indicate generally a straight line, an equation of the form $a = KR^n$ was applicable, where "a" is either the crest elevation above still water or the difference in elevation between crest and trough, "K" is a factor which varies with charge position and weight, "R" is the radial distance along the water surface from the charge to the gage, and "n" is an exponent indicating the rate of decay of the wave. Tables E and F show the values of n for a_{+1} and $a_{+1} + a_{-1}$, respectively, for the first wave. These values were computed by the method of least squares for each charge weight and position.

43. The averages of all values of n in tables E and F indicate that the height of the first wave varied as functions of $R^{-1.09}$ to $R^{-0.6}$. Additional study of photographic records is being made in an effort to narrow the range of scatter of these values.

Table E

Values of "n" from Equation $a_{+1} = KR^n$

Charge Weight(W)	Charge Position (Z) 0.5D	0	-1.0D	-2.5D	-4.0D
0.5	-0.54	-0.70	-1.49	-0.48	-0.92
4	-0.61	-1.21	-0.81	-0.66	-0.81
16	-2.44	-1.58	-1.24	-1.29	-0.97
32	-1.67	-1.24	-1.22	-1.10	-1.38
256	---	---	-1.08	-0.78	---
2048	---	---	-0.89	---	---

Average of all values = -1.09

Table F

Values of "n" from Equation $a_{+1} + a_{-1} = KR^n$

Charge Weight(W)	Charge Position (Z) 0.5D	0	-1.0D	-2.5D	-4.0D
0.5	-0.31	-0.24	-0.87	-0.22	0.26*
4	-0.42	-0.74	-0.53	-0.38	-0.84
16	-1.08	-0.18	-0.96	---	0.02*
32	-0.28	0.18*	-0.77	-0.64	-0.57
256	---	---	-1.36	-0.68	---
2048	---	---	-0.29	---	---

Average of all values = -0.60

* Not included in average.

Effect of charge weight

44. Plates 47-52 show the effect of charge weight on wave height, and the values of n in the equations $a_{+1} = KW^n$ (crest height as a function of charge weight) and $a_{+1} + a_{-1} = KW^n$ (total wave as a function

of charge weight) are presented in tables G and H below. These values were computed by the method of least squares.

Table G

Values of "n" from Equation $a_{+1} = KW^n$

Gage Location(R/D)	Charge Position (Z) 0.5D	0	-1.0D	-2.5D	-4.0D
60	0.27	0.29	0.32	0.36	0.34
100	0.40	0.39	0.36	0.42	0.06
200	0.11	0.28	0.46	0.36	0.24
Average	0.26	0.32	0.38	0.38	0.21

Average of all values = 0.31

Table H

Values of "n" from Equation $a_{+1} + a_{-1} = KW^n$

Gage Location(R/D)	Charge Position (Z) 0.5D	0	-1.0D	-2.5D	-4.0D
60	0.15	0.18	0.30	0.26	0.44
100	0.17	0.24	0.29	0.39	0.07
200	0.15	0.35	0.37	0.29	0.11
Average	0.16	0.26	0.32	0.31	0.21

Average of all values = 0.25

45. Although these average values vary slightly from those presented in previous reports, their order of magnitude and the range of scatter of the individual values are consistent with previous results (Report No. 2).

Discussion of results

46. The results of water wave measurements presented herein are, as previously stated, limited to what appeared to be the first and second crest and trough recorded on each wave rod. Preliminary analysis of photographic data, however, shows that wave records have been affected considerably by fall-out of bottom material, and that a wave of a more regular pattern, which may have resulted from the explosion, moved radially outward some time after the fall out. Investigations of photographic data are being continued and all wave records are being re-examined to determine whether or not a gravity-type wave, similar to that found in the scaled 200-ft water depth, was formed in these tests. There is no evidence, however, which indicates that wave heights previously reported, or those reported herein, for the scaled 30-ft depth will be changed appreciably as the result of this study.

Test Results -- Air Blast

47. Plate 53 shows typical air-blast records. These records were obtained from a 16-lb charge fired at the bottom. The five digit number appearing at the top identifies each record. The first digit identifies the channel or oscilloscope from which the record was obtained and the remaining digits identify the shot number. The dots near the base of the record are timing marks which have a normal interval of two and one-half milliseconds (2.5 ms); however, intervals as long as ten milliseconds were used to record the air blast from the large field-test shots. In

addition to the pressure-time traces (A), the records have two callibration steps (B) which were made before and after the charge was detonated. The recording equipment was connected to the firing circuit so that the beam which made the pressure-time trace on the film would brighten when the firing switch was closed and would remain bright for one revolution of the drum camera. The timing dots were recorded simultaneously with the pressure-time trace.

Analysis of pressure-time records

48. The film strip pressure-time records were enlarged to approximately eight times their normal size by placing them in a Vu-Graph projector and projecting them against a wall. Pertinent sections of the enlargement were then traced on regular coordinate paper, such as the pressure-time curve of the shock wave, the vertical deflection of the calibration steps, and enough timing dots to determine the time scale. The length of the time-of-arrival line was measured directly on the enlargement and noted on the tracing. This tracing then became the work sheet for the computation of blast-pressure phenomena. A typical work sheet is shown on plate 54. The calibration factor was computed by applying the gage factor, shunt capacitance, and calibration voltage to the calibration deflection. The peak pressure was obtained by extending the pressure-time curve upward to where it intersected a vertical line drawn through the midpoint of the pressure rise line and applying the calibration factor to the resulting deflection. Time of arrival and durations of positive and negative pressures were computed by multiplying

their measured length by the time scale obtained from the timing dots. The areas bounded by the pressure-time curves and the base line were planimetered and multiplied by the impulse scale (product of pressure scale and time scale) to obtain the positive and negative impulses. Average velocities, charge-to-gage, were computed by dividing the distance from the charge to the gage by the time of arrival of the shock wave; and the gage-to-gage velocities were obtained by dividing the distance between successive gages by the difference in arrival times. A sample set of calculations is given in the Appendix.

Test data

49. Results of air-blast measurements obtained from shots fired in the WES test basin are presented in tables 7-24, while results obtained from the field-test shots are listed in tables 25-30. Shot numbers are repeated in the tables where more than one gage was located at the same distance from the charge. These tables list the values computed for each record and also give the arithmetic mean and the standard deviation of the mean for each set of values.

50. A resume of all peak pressure data obtained in the tests is presented on plate 55, which shows the variation of the average peak pressures for each charge weight with reduced distances (λ) for the various charge positions. The curves and accompanying equations shown were computed by assuming that the values obtained from all charges, except the 0.5-lb charge, plotted as a straight line and that an equation of the form $p = K\lambda^n$ could be written for each charge position. Since

results obtained from the 0.5-lb charges obviously plotted in a lower range for nearly all charge positions, these data were omitted from the computations. The effect of charge position on peak pressure is shown on plate 56, where peak pressure vs reduced distance curves are plotted for each charge position. Reduced positive impulse is presented in a similar manner on plates 57 and 58. Most of the blast records showed an appreciable negative phase following the decay of the shock wave. Although there was considerable scatter in the measurements, the data obtained from the negative portion of the blast-wave records also are listed in tables 7-30. It was first thought that the lack of low-frequency response of cathode followers in the air-blast recording instrumentation was affecting the values of negative pressures. However, after a review of the capabilities of air-blast instrumentation, including discussions with Dr. A. B. Arons, Consultant on the project, it was concluded that a reasonable degree of accuracy could be expected of measurements in the negative portion of the blast wave. Pending further analysis of these portions of the records for possible minor corrections, the data are presented only in tabular form in this report.

Discussion of results - air blast

51. The results of air-blast measurements indicate a close agreement with the cube root scaling law as evidenced by the conformity of the peak pressures and values of reduced positive impulse listed in tables 7-30. Results obtained with the 0.5-lb charge were not generally in agreement with results for other charge weights and were therefore

omitted in the computations for developing the equations given on plates 55 and 57. Charges detonated at and slightly above the water surface yielded peak pressures of the same magnitude beyond a scaled distance of $\lambda = 10$. At lesser scaled distances the charge fired at $Z = 0.5D$ gave slightly higher pressures (plate 56). At $\lambda = 6$, pressures were reduced approximately 30 per cent when the charge was detonated at the bottom as compared with the surface shot; however, the rate of attenuation of the shock wave was indicated to be less than those for the two higher charge positions since the three lines tend to converge at $\lambda = 20$ (plate 56). Charges detonated at scaled distances of 45 and 90 ft below the bottom effected considerable reductions in peak pressures throughout the range of measurements. It is of interest to compare the experimental pressures with pressures which would have been obtained had the tests been performed in the free air region. Such a comparison is made in table I below for three pressure levels, where the "equivalent weight in free air" is defined as the ratio of the charge weight required to produce the given pressure level in free air to the weight of the experimental charge at the various charge positions which will give the same pressure at the same radial distance. The table shows, for example, that a charge positioned at -2.5D must be 8 times the weight of a charge in free air to produce a pressure of 10 psi at the same distance from the charge.

Table I

Equivalent Charge Weight in Free Air

Charge Position(Z)	Pressure Levels, Psi		
	20	10	5
0.5D	1.08	1.37	1.44
0	0.79	1.13	1.36
-1.0D	0.30	0.61	1.10
-2.5D	----	0.13	0.32
-4.0D	----	----	0.06

52. The plots of reduced positive impulse shown on plate 58 indicate that an appreciable reduction in impulse is effected by placing the charge at the bottom in a relatively shallow water depth as compared to charges fired at or slightly above the water surface. Charges placed 45 to 90 ft below the bottom reduce the magnitude of impulse by factors ranging from 50 to 65 per cent, depending on the distance from the charge and charge position.

Abbreviations and Symbols

A area of crater in sq ft

a_{+1} crest height of first surface wave in ft

a_{-1} trough depth behind first surface wave in ft

$a_1 = a_{+1} + a_{-1}$

a_{+2} crest height of second surface wave in ft

a_{-2} trough depth behind second surface wave in ft

$a_2 = a_{+2} + a_{-2}$

c celerity or velocity of the surface wave in ft per sec

D depth of water in ft

d maximum depth of apparent crater in ft (after collapse of crater lip)

d_1 maximum depth of apparent crater in ft (before collapse of crater lip)

h height of crater lip in ft

I positive impulse in lb-ms per sq in

m milli

ms millisecond

P any parameter in the general empirical formula $P = KW^n$, where K is a constant and n is the exponent of W

p peak pressure in lb per sq in

R horizontal distance from charge in ft

r radius of crater (w/2) in ft

t time in sec

V volume of crater in cu ft

Abbreviations and Symbols (Cont'd)

W value of energy release, or weight of charge in lb

w width of crater in ft

w' width of crater lip in ft

X, Y standard rectangular coordinates from any designated point of origin in ft

Z charge position, distance from water surface to charge center of gravity expressed in terms of the total water depth

λ $R/W^{1/3}$ (reduced distance)

μ micro

PHOTOGRAPHS

Crater formed by 16-lb charge detonated one-half water depth above water surface
Scaled water depth, 30 ft

PHOTOGRAPH 1

Crater formed by 16-lb charge detonated at water surface
Scaled water depth, 30 ft

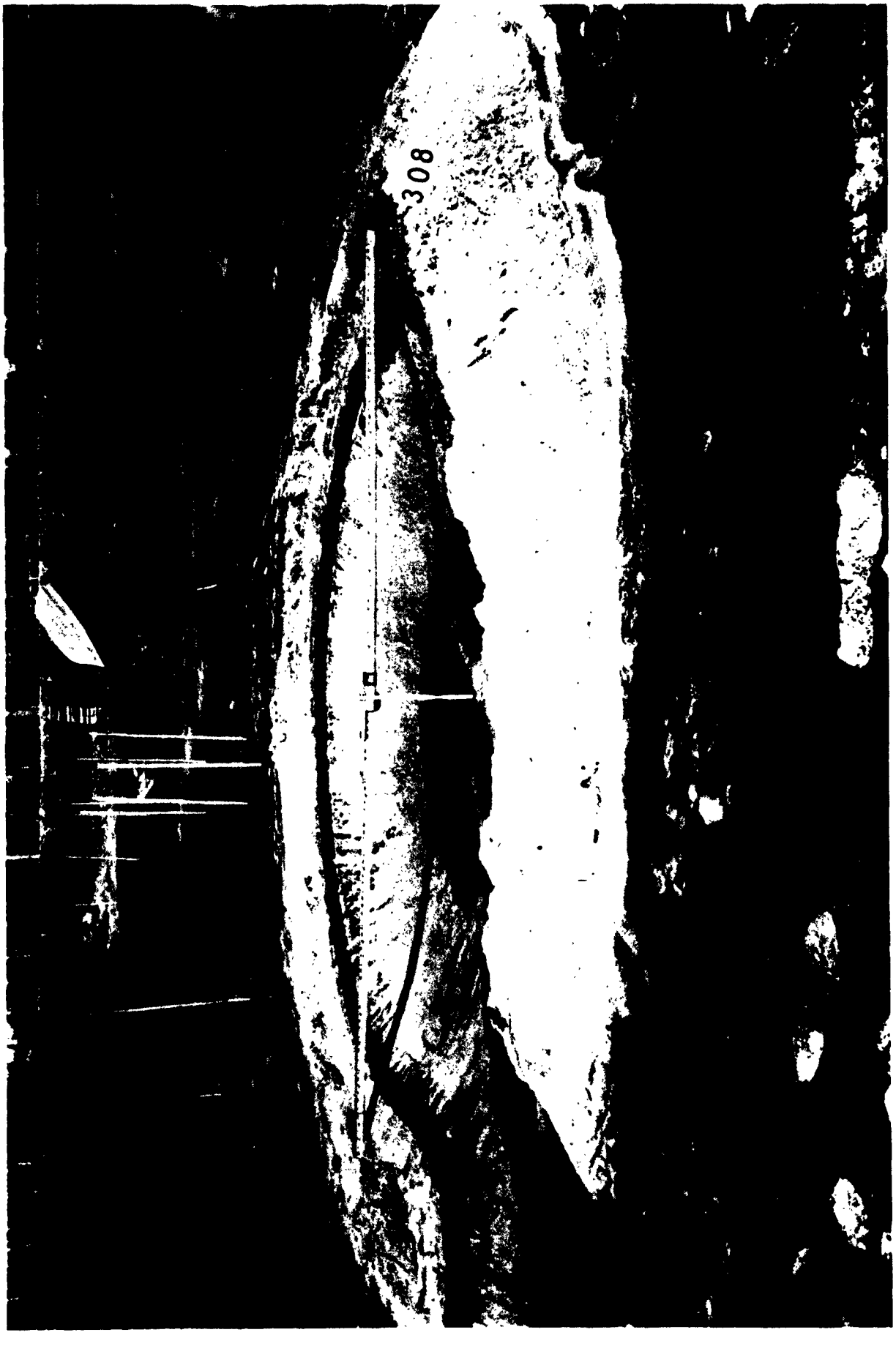
PHOTOGRAPH 2

Crater formed by 16-lb charge detonated at bottom
Scaled water depth, 30 ft

PHOTOGRAPH 3

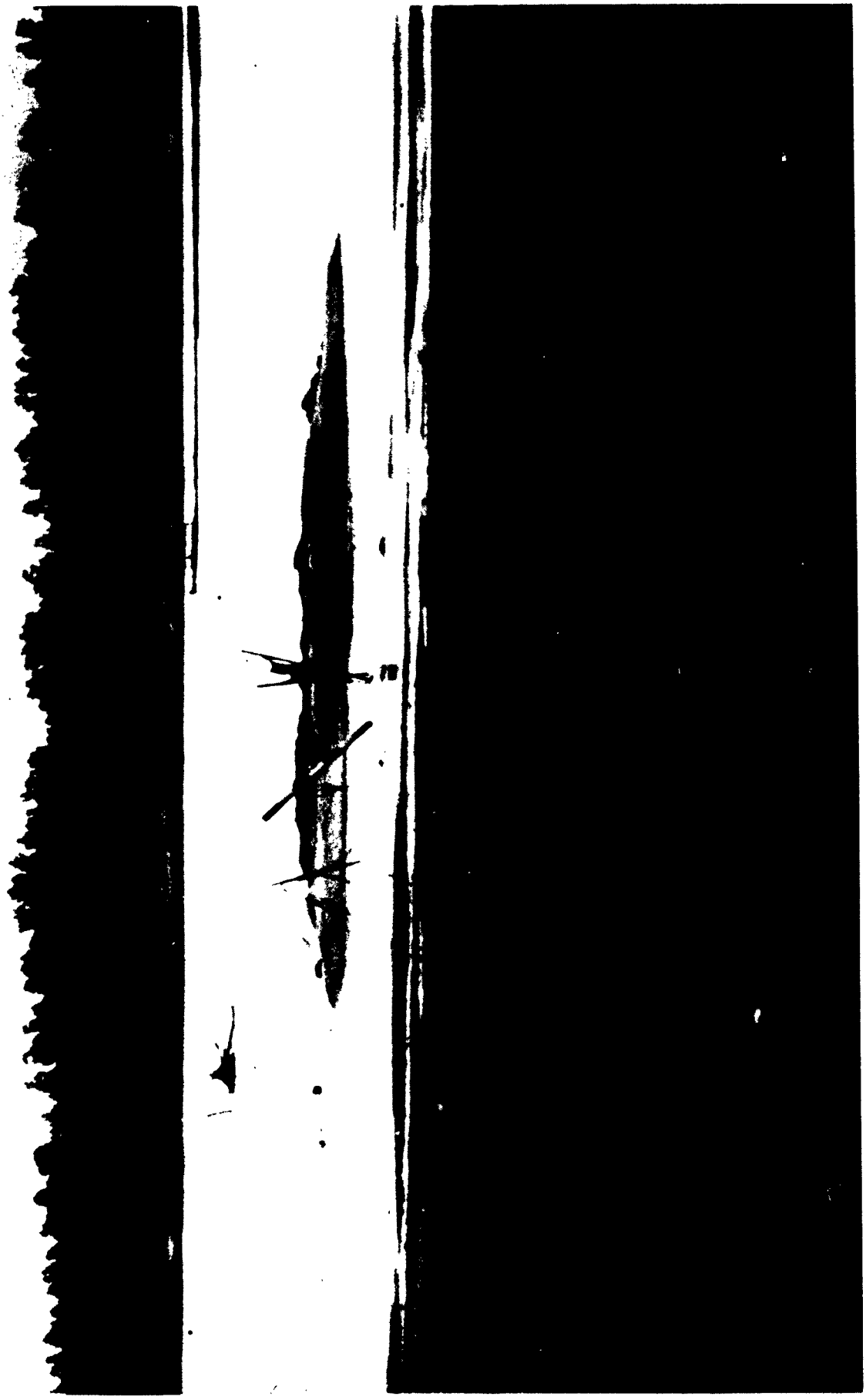
Crater formed by 16-lb charge detonated at a scaled depth of 45 ft below bottom
Scaled water depth, 30 ft

PHOTOGRAPH 4



Crater formed by 16-lb charge detonated at a scaled depth of 90 ft below bottom
Scaled water depth, 30 ft

PHOTOGRAPH 5



Crater formed by 256-lb charge detonated at bottom
Scaled water depth, 30 ft

PHOTOGRAPH 6

TABLES

TABLE 1

RESULTS OF CRATERING TESTS IN SAND - 0.5-LB CHARGES

$D/W^{1/3} = 0.088$

Charge Position (Z)*	Shot No.	Water Depth D(ft)	Crater Dimensions: Max Depth d (ft)	Max Depth d_1(ft)	Max Width w (ft)	Height of Lip h (ft)	Width of Lip w' (ft)	Reduced Crater Dimensions: $d/W^{1/3}$	$d_1/W^{1/3}$	$w/W^{1/3}$	$h/W^{1/3}$	$w'/W^{1/3}$
Charge below bottom (Z = -4.0D)**	284	0.07	1.02	****	3.61	0.12	1.70	1.28	___	4.55	0.15	2.14
	285	0.07	0.93	1.12	3.41	0.14	1.80	1.17	1.41	4.29	0.18	2.27
	286	0.07	0.92	****	3.15	0.14	1.93	1.16	___	3.97	0.18	2.43
Mean values		0.07	0.96	1.12	3.39	0.13	1.81	1.20	1.41	4.27	0.17	2.28
Standard deviation of the mean			±0.03	0.00	±0.13	±0.01	±0.07	±0.04	0.00	±0.16	±0.01	±0.09
Charge below bottom (Z = -2.5D)***	281	0.07	0.67	0.79	2.97	0.12	2.02	0.84	0.99	3.74	0.15	2.54
	282	0.07	0.66	1.01	3.09	0.12	1.93	0.83	1.27	3.89	0.15	2.43
	283	0.07	0.64	****	2.94	0.12	2.04	0.81	___	3.70	0.15	2.57
Mean values		0.07	0.66	0.90	3.00	0.12	2.00	0.83	1.13	3.78	0.15	2.51
Standard deviation of the mean			±0.01	±0.11	±0.05	0.00	±0.04	±0.01	±0.14	±0.06	0.00	±0.05
Charge at bottom (Z = -1.0D)	278	0.07	0.44	****	2.36	0.13	2.33	0.55	___	2.97	0.16	2.93
	279	0.07	0.53	****	2.75	0.04	1.11	0.67	___	3.46	0.05	1.40
	280	0.07	0.54	****	2.76	0.07	1.63	0.68	___	3.48	0.09	2.05
Mean values		0.07	0.50	___	2.62	0.08	1.69	0.63	___	3.30	0.10	2.13
Standard deviation of the mean			±0.01	___	±0.13	±0.03	±0.35	±0.01	___	±0.16	±0.04	±0.44
Charge at surface (Z = 0)	287	0.07	0.37	****	2.50	0.06	1.88	0.47	___	3.15	0.08	2.37
	288	0.07	0.30	****	2.55	0.05	1.73	0.38	___	3.21	0.06	2.18
	289	0.07	0.28	****	2.20	0.11	1.25	0.35	___	2.77	0.14	1.57
Mean values		0.07	0.32	___	2.42	0.07	1.62	0.40	___	3.04	0.09	2.04
Standard deviation of the mean			±0.03	___	±0.11	±0.02	±0.19	±0.04	___	±0.14	±0.03	±0.24
Charge above surface (Z = 0.5D)	290	0.07	0.30	****	2.72	0.01	0.63	0.38	___	3.43	0.01	0.79
	296	0.07	0.32	****	1.94	0.04	2.03	0.40	___	2.44	0.05	2.56
	297	0.07	0.35	****	2.44	0.04	0.80	0.44	___	3.07	0.05	1.11
Mean values		0.07	0.32	___	2.37	0.03	1.15	0.41	___	2.98	0.04	1.45
Standard deviation of the mean			±0.01	___	±0.22	±0.01	±0.44	±0.01	___	±0.28	±0.01	±0.55

* Charge Position (Z) denotes, in terms of total water depth (D), the distance above or below the water surface to the charge center of gravity.

** Full-scale depth below bottom--90 ft.

*** Full-scale depth below bottom--45 ft.

**** Unreliable or no data obtained.

TABLE 2

RESULTS OF CRATERING TESTS IN SAND - 4-LB CHARGES

$D/Wl/3 = 0.088$

Charge Position (Z)*	Shot No.	Water Depth D(ft)	Crater Dimensions: Max Depth d (ft)	Max Depth d_1(ft)	Max Width w (ft)	Height of Lip h (ft)	Width of Lip w' (ft)	Reduced Crater Dimensions: $d/Wl/3$	$d_1/Wl/3$	$w/Wl/3$	$h/Wl/3$	$w'/Wl/3$
Charge below bottom (Z = -4.0D)**	267	0.14	1.18	1.78	6.96	0.25	4.52	0.74	1.12	4.38	0.16	2.84
	269	0.14	1.23	1.55	7.66	0.29	4.18	0.77	0.97	4.82	0.18	2.63
	274	0.14	1.24	1.42	7.56	0.30	4.23	0.78	0.89	4.75	0.19	2.66
Mean values		0.14	1.22	1.58	7.39	0.28	4.31	0.76	0.99	4.65	0.18	2.71
Standard deviation of the mean			±0.02	±0.10	±0.22	±0.01	±0.09	±0.01	±0.06	±0.14	±0.01	±0.06
Charge below bottom (Z = -2.5D)***	264	0.14	0.91	1.56	6.00	0.24	2.97	0.57	0.98	3.77	0.15	1.87
	265	0.14	0.98	1.55	6.33	0.24	2.88	0.62	0.97	3.98	0.15	1.81
	266	0.14	1.12	****	6.57	0.22	2.70	0.70	——	4.13	0.14	1.70
Mean values		0.14	1.00	1.56	6.30	0.23	2.85	0.63	0.98	3.96	0.15	1.79
Standard deviation of the mean			±0.06	0.00	±0.17	±0.01	±0.08	±0.04	0.00	±0.11	±0.01	±0.05
Charge at bottom (Z = -1.0D)	254	0.14	0.70	1.29	5.55	0.19	3.22	0.44	0.81	3.49	0.12	2.03
	255	0.14	0.70	1.20	5.80	0.14	3.10	0.44	0.75	3.65	0.09	1.95
	256	0.14	0.70	1.49	5.75	0.30	3.12	0.44	0.94	3.62	0.19	1.96
Mean values		0.14	0.70	1.33	5.70	0.21	3.15	0.44	0.83	3.59	0.13	1.98
Standard deviation of the mean			0.00	±0.09	±0.08	±0.05	±0.04	0.00	±0.06	±0.05	±0.03	±0.03
Charge at surface (Z = 0)	261	0.14	0.72	****	5.14	0.16	2.93	0.45	——	3.23	0.10	1.84
	262	0.14	0.75	****	4.84	0.14	2.59	0.47	——	3.04	0.09	1.63
	263	0.14	0.73	****	4.66	0.15	2.67	0.46	——	2.93	0.09	1.68
Mean values		0.14	0.73	——	4.88	0.15	2.73	0.46	——	3.07	0.09	1.72
Standard deviation of the mean			±0.01	——	±0.14	±0.01	±0.10	±0.01	——	±0.09	±0.01	±0.06
Charge above surface (Z = 0.5D)	270	0.14	0.71	****	3.80	0.22	2.62	0.45	——	2.39	0.14	1.65
	272	0.14	0.73	****	4.35	0.19	2.83	0.46	——	2.74	0.12	1.78
	273	0.14	0.75	****	4.10	0.22	2.95	0.47	——	2.58	0.14	1.86
Mean values		0.14	0.73	——	4.08	0.21	2.80	0.46	——	2.57	0.13	1.76
Standard deviation of the mean			±0.01	——	±0.16	±0.01	±0.10	±0.01	——	±0.10	±0.01	±0.06

* Charge Position (Z) denotes, in terms of total water depth (D), the distance above or below the water surface to the charge center of gravity.

** Full-scale depth below bottom--90ft.

*** Full-scale depth below bottom--45ft.

**** Unreliable or no data obtained.

TABLE 3

RESULTS OF CRATERING TESTS IN SAND - 16-LB CHARGES

$D/W^{1/3} = 0.068$

Charge Position (Z)*	Shot No.	Water Depth D(ft)	Crater Dimensions: Max Depth d (ft)	Max Depth d_1(ft)	Max Width w (ft)	Height of Lip h (ft)	Width of Lip w' (ft)	Reduced Crater Dimensions: $d/W^{1/3}$	$d_1/W^{1/3}$	$w/W^{1/3}$	$h/W^{1/3}$	$w'/W^{1/3}$
Charge below bottom (Z = -4.0D)**	307	0.22	1.45	3.09	11.94	0.40	4.03	0.58	1.23	4.74	0.16	1.60
	308	0.22	1.19	2.89	11.94	0.57	4.03	0.47	1.15	4.74	0.23	1.60
	309	0.22	****	2.92	****	****	****	___	1.16	___	___	___
Mean values		0.22	1.32	2.97	11.94	0.49	4.03	0.53	1.18	4.74	0.20	1.60
Standard deviation of the mean			±0.13	±0.06	0.00	±0.08	0.00	±0.05	±0.02	0.00	±0.03	0.00
Charge below bottom (Z = -2.5D)***	310	0.22	1.32	2.54	10.54	0.53	4.73	0.52	1.01	4.18	0.21	1.88
	311	0.22	1.19	2.67	10.30	0.51	4.86	0.47	1.06	4.09	0.20	1.93
	313	0.22	1.16	2.38	9.52	0.43	5.24	0.46	0.94	3.78	0.17	2.08
Mean values		0.22	1.22	2.53	10.12	0.49	4.94	0.48	1.00	4.02	0.19	1.96
Standard deviation of the mean			±0.05	±0.08	±0.30	±0.03	±0.15	±0.02	±0.03	±0.12	±0.01	±0.06
Charge at bottom (Z = -1.0D)	298	0.22	0.88	2.01	8.20	0.47	4.90	0.35	0.80	3.25	0.19	1.94
	304	0.22	0.83	****	7.64	0.39	5.20	0.33	___	3.03	0.15	2.06
	305	0.22	0.80	1.97	7.72	0.47	5.13	0.32	0.78	3.06	0.19	2.04
Mean values		0.22	0.84	1.99	7.85	0.44	5.08	0.33	0.79	3.11	0.18	2.01
Standard deviation of the mean			±0.02	±0.02	±0.17	±0.03	±0.09	±0.01	±0.01	±0.07	±0.01	±0.04
Charge at surface (Z = 0)	314	0.22	0.82	****	6.90	0.28	4.55	0.33	___	2.74	0.11	1.81
	315	0.22	0.84	****	7.50	0.35	4.25	0.33	___	2.98	0.14	1.69
	325	0.22	0.98	****	7.60	0.38	4.20	0.35	___	3.02	0.15	1.67
Mean values		0.22	0.85	___	7.33	0.34	4.33	0.34	___	2.91	0.13	1.72
Standard deviation of the mean			±0.02	___	±0.22	±0.03	±0.11	±0.01	___	±0.09	±0.01	±0.04
Charge above surface (Z = 0.5D)	319	0.22	0.63	1.38	6.27	0.31	4.35	0.25	0.55	2.49	0.12	1.73
	326	0.22	1.06	****	6.75	0.29	4.15	0.42	___	2.68	0.12	1.65
	329	0.22	1.09	****	6.90	0.08	4.05	0.43	___	2.74	0.03	1.61
Mean values		0.22	0.93	1.38	6.64	0.23	4.18	0.37	0.55	2.64	0.09	1.66
Standard deviation of the mean			±0.15	0.00	±0.19	±0.07	±0.09	±0.06	0.00	±0.08	±0.03	±0.04

* Charge Position (Z) denotes, in terms of total water depth (D), the distance above or below the water surface to the charge center of gravity.

** Full-scale depth below bottom--90 ft.

*** Full-Scale depth below bottom--45 ft.

**** Unreliable or no data obtained.

TABLE 4

RESULTS OF CRATERING TESTS IN SAND - 32-LB CHARGES

$D/W^{1/3} = 0.088$

Charge Position (Z)*	Shot No.	Water Depth D(ft)	Crater Dimensions: Max Depth d (ft)	Max Depth d_1(ft)	Max Width w (ft)	Height of Lip h (ft)	Width of Lip w' (ft)	Reduced Crater Dimensions: $d/W^{1/3}$	$d_1/W^{1/3}$	$w/W^{1/3}$	$h/W^{1/3}$	$w'/W^{1/3}$
Charge below bottom (Z = -4.0D)**	323	0.28	2.15	3.31	13.70	0.74	3.15	0.68	1.04	4.32	0.23	0.99
	333	0.28	2.24	3.39	16.20	0.54	1.92	0.71	1.07	5.11	0.17	0.61
	334	0.28	1.82	3.30	17.10	0.81	3.45	0.57	1.04	5.39	0.26	1.09
Mean values		0.28	2.07	3.33	15.67	0.70	2.84	0.65	1.05	4.94	0.22	0.90
Standard deviation of the mean			±0.13	±0.03	±1.01	±0.08	±0.47	±0.04	±0.01	±0.32	±0.03	±0.15
Charge below bottom (Z = -2.5D)***	331	0.28	1.41	2.93	13.06	0.67	3.47	0.44	0.92	4.12	0.21	1.09
	332	0.28	1.72	3.26	13.50	0.54	3.25	0.54	1.03	4.26	0.17	1.03
	336	0.28	1.50	2.93	12.94	0.55	3.53	0.47	0.92	4.08	0.17	1.11
Mean values		0.28	1.54	3.04	13.17	0.59	3.42	0.48	0.96	4.15	0.18	1.08
Standard deviation of the mean			±0.09	±0.11	±0.17	±0.04	±0.08	±0.03	±0.03	±0.05	±0.01	±0.03
Charge at bottom (Z = -1.0D)	330	0.28	1.31	2.69	10.88	0.54	4.56	0.41	0.85	3.43	0.17	1.44
	337	0.28	1.03	2.45	11.66	0.54	4.17	0.32	0.77	3.68	0.17	1.32
	338	0.28	1.08	2.65	12.08	0.46	3.96	0.34	0.84	3.81	0.15	1.25
Mean values		0.28	1.14	2.60	11.54	0.51	4.23	0.36	0.82	3.64	0.16	1.34
Standard deviation of the mean			±0.09	±0.07	±0.35	±0.03	±0.18	±0.03	±0.02	±0.11	±0.01	±0.06

* Charge Position (Z) denotes, in terms of total water depth (D), the distance above or below the water surface to the charge center of gravity.

** Full-scale depth below bottom--90ft.

*** Full-scale depth below bottom--45ft.

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TABLE 5

RESULTS OF CRATERING TESTS IN SAND

$D/W^{1/3} = 0.088$

Crater Parameter*	Values for W1/3 Law K	Values for W1/3 Law n	Mean Experimental Values K	Mean Experimental Values n
Charge below bottom (Z = -4.0D)				
Width - w	4.65	0.333	4.39	0.366
Depth - d	0.79	0.333	1.02	0.157
Lip Height - h	0.19	0.333	0.17	0.400
Area - A	2.37	0.667	2.70	0.584
Volume - V	6.35	1.000	6.47	0.989
Charge below bottom (Z = -2.5D)				
Width - w	3.98	0.333	3.84	0.354
Depth - d	0.61	0.333	0.75	0.195
Lip Height - h	0.17	0.333	0.15	0.396
Area - A	1.59	0.667	1.79	0.594
Volume - V	3.76	1.000	3.90	0.977
Charge at bottom (Z = -1.0D)				
Width - w	3.41	0.333	3.38	0.339
Depth - d	0.44	0.333	0.55	0.183
Lip Height - h	0.17	0.333	0.11	0.461
Area - A	1.03	0.667	1.12	0.617
Volume - V	1.67	1.000	2.10	1.007
Charge at surface (Z = 0)				
Width - w	3.01	0.333	3.05	0.321
Depth - d	0.40	0.333	0.42	0.291
Lip Height - h	0.10	0.333	0.09	0.449
Area - A	0.79	0.667	0.80	0.652
Volume - V	1.35	1.000	1.30	1.020
Charge above surface (Z = 0.5D)				
Width - w	2.73	0.333	2.85	0.294
Depth - d	0.41	0.333	0.44	0.301
Lip Height - h	**	**	**	**
Area - A	0.67	0.667	0.66	0.680
Volume - V	1.01	1.000	0.98	1.025

*$P = KW^n$ where:

P = specified parameter
K = constant
W = charge weight in lbs
n = exponent of charge weight

** = Unreliable data

Charge position (Z) denotes, in terms of total water depth (D), the distance above or below the water surface to the charge center of gravity.

TABLE 6

RESULTS OF CRATERING TESTS IN SAND

(INCLUDES WES BASIN AND FIELD TEST DATA)

CHARGE AT BOTTOM (Z = -1.0D)

$D/W^{1/3} = 0.088$

Crater Parameter*	Values for $W^{1/3}$ Law		Mean Experimental Values	
	K	n	K	n
Width - w	3.59	0.333	3.30	0.357
Depth - d	0.42	0.333	0.50	0.269
Lip Height - h	0.17	0.333	0.12	0.430
Area - A	1.03	0.667	1.10	0.645
Volume - V	2.26	1.000	2.13	1.011

*$P = KW^n$ where:

P = specified parameter
K = constant
W = charge weight in lbs
n = exponent of charge weight

Charge position (Z) denotes, in terms of total water depth (D), the distance above or below the water surface to the charge center of gravity.

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TABLE 7

RESULTS OF AIR-BLAST MEASUREMENTS - 0.5-LB CHARGES

$D/W^{1/3}$ = 0.088; BOTTOM MATERIAL - SAND

CHARGE POSITION - ABOVE SURFACE (Z = 0.5D)

Gage Distance (ft)	Reduced Distance λ ($ft/lb^{1/3}$)	Shot No.*	Peak Pressure (psi)	Positive Impulse ($lb\text{-}ms/in^2$)	Reduced Positive Impulse ($lb\text{-}ms/in^2/lb^{1/3}$)	Positive Duration (ms)	Negative Impulse ($lb\text{-}ms/in^2$)	Negative Duration (ms)	Arrival Time (ms)	Avg Velocity Charge to Gage (ft/sec)	Avg Velocity Gage to Gage (ft/sec)
4.76	6	290	14.16	6.08	7.66	1.11	8.31	4.83	1.59	2994	
		290	15.92	5.82	7.33	0.93	8.62	4.50	1.59	2994	
		296	14.10	6.16	7.76	1.21	10.19	5.27	1.78	2674	
		296	15.22	6.09	7.67	0.96	9.96	4.66	1.58	3013	
		297	16.51	6.18	7.79	1.13	8.34	5.06	1.62	2938	
		297	16.51	6.19	7.80	0.97	10.84	5.03	1.61	2957	
Mean values			15.40	6.09	7.67	1.05			1.63	2928	
Standard deviation of the mean			±0.45	±0.06	±0.07	±0.02			±0.03	±25	
7.94	10	290	7.01								
		290	6.91								
		296	6.67	4.37	5.51	1.85	6.24	5.91	3.94	2015	1472
		296	7.37	4.17	5.25	1.71	9.21	7.31	3.94	2015	1347
		297	7.93	4.53	5.71	1.92	9.28	6.55	3.79	2095	1465
		297	7.29	4.98	6.27	1.85	7.17	6.03	3.79	2095	1459
Mean values			7.20	4.51	5.69	1.83			3.87	2055	1436
Standard deviation of the mean			±0.18	±0.17	±0.22	±0.04			±0.04	±23	±30
11.91	15	290	3.62	2.74	3.45	2.02	3.52	6.15	6.49	1835	
		296	3.50	2.78	3.50	2.03	3.83	5.74	6.79	1754	1393
		297	3.78	2.97	3.74	2.09	3.94	6.10	6.58	1810	1423
Mean values			3.63	2.83	3.56	2.05			6.62	1800	1408
Standard deviation of the mean			±0.08	±0.05	±0.09	±0.02			±0.09	±24	±15
15.87	20	290	2.48	2.30	2.90	2.30	2.81	5.11	9.79	1621	1200
		296	2.37	2.28	2.87	2.62	3.06	5.51	10.15	1564	1179
		297	2.41	2.18	2.75	2.42	2.27	5.10	9.89	1605	1196
Mean values			2.42	2.25	2.84	2.45			9.94	1597	1192
Standard deviation of the mean			±0.03	±0.03	±0.05	±0.10			±0.11	±17	±7

*Shot number repeated where more than one gage used at a particular location.

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TABLE 8

RESULTS OF AIR-BLAST MEASUREMENTS - 0.5-LB CHARGES

$D/W^{1/3}$ = 0.088; BOTTOM MATERIAL - SAND

CHARGE POSITION - AT SURFACE (Z = 0)

Gage Distance (ft)	Reduced Distance λ ($ft/lb^{1/3}$)	Shot No.*	Peak Pressure (psi)	Positive Impulse ($lb\text{-}ms/in^2$)	Reduced Positive Impulse ($lb\text{-}ms/in^2/lb^{1/3}$)	Positive Duration (ms)	Negative Impulse ($lb\text{-}ms/in^2$)	Negative Duration (ms)	Arrival Time (ms)	Avg Velocity Charge to Gage (ft/sec)	Avg Velocity Gage to Gage (ft/sec)
4.76	6	287	16.60	6.52	8.21	1.19	8.48	5.13	1.62	2938	
		287	15.04	5.70	7.18	0.91	11.77	5.23	1.56	3051	
		288	14.36	6.05	7.62	1.29	6.60	4.63	1.69	2817	
		288	14.84	6.12	7.71	0.93	12.24	5.48	1.69	2817	
		289	13.64	5.97	7.52	1.22	9.25	5.05	1.78	2674	
		289	13.12	5.92	7.46	1.30	6.74	3.91	1.62	2938	
		442	14.49	6.17	7.77	1.16			1.56	3051	
		443	10.36	4.46	5.62	0.97	12.67	5.48	1.63	2920	
		443	12.16	5.45	6.87	1.21	11.09	5.25	1.88	2532	
		473	14.14	6.44	8.11	0.91	6.44	4.03	1.61	2957	
		473	15.66	6.49	8.18	0.94	11.55	5.84	1.41	3376	
Mean values			14.04	5.94	7.48	1.09			1.64	2916	
Standard deviation of the mean			±0.51	±0.18	±0.22	±0.05			±0.04	±61	
7.94	10	287	7.42								
		287	7.42								
		288	6.49								
		288	6.08								
		289	8.04								
		289	6.12								
		442	7.01	4.43	5.58	1.67			3.75	2117	1452
		442	6.90	4.54	5.72	1.69	3.92	4.89	3.46	2295	1674
		442	8.11	4.94	6.22	1.87	6.40	5.99	3.42	2322	1710
		443	6.67	4.42	5.57	1.61	7.56	5.16	3.55	2237	1656
		443	6.40	4.21	5.30	1.62	7.00	5.05	4.15	1913	1401
		443	6.15	4.37	5.51	1.79	4.45	5.30	3.80	2089	1465
		443	7.05	4.45	5.61	1.44	7.21	6.86	3.65	2175	1797
		443	5.65	3.98	5.01	1.82	3.98	6.38	3.57	2224	1639
		443	6.36	3.68	4.64	1.62	5.99	5.69	3.51	2262	1951
		473	6.20	3.53	4.45	1.48	6.66	5.75	3.84	2068	1426
		473	7.58	4.27	5.38	1.57	5.83	4.40	3.78	2101	1465
		473	6.45	4.50	5.67	1.91	4.56	5.53	3.69	2152	1395
Mean values			6.78	4.28	5.39	1.67			3.68	2163	1586
Standard deviation of the mean			±0.17	±0.11	±0.14	±0.04			±0.06	±30	±51

*Shot number repeated where more than one gage used at a particular location.

TABLE 8 (CONTD)

RESULTS OF AIR-BLAST MEASUREMENTS - 0.5-LB CHARGES

$D/W^{1/3}$ = 0.088; BOTTOM MATERIAL - SAND

CHARGE POSITION - AT SURFACE (Z = 0)

Gage Distance (ft)	Reduced Distance λ ($ft/lb^{1/3}$)	Shot No.	Peak Pressure (psi)	Positive Impulse ($lb\text{-}ms/in^2$)	Reduced Positive Impulse ($lb\text{-}ms/in^2/lb^{1/3}$)	Positive Duration (ms)	Negative Impulse ($lb\text{-}ms/in^2$)	Negative Duration (ms)	Arrival Time (ms)	Avg Velocity Charge to Gage (ft/sec)	Avg Velocity Gage to Gage (ft/sec)
11.91	15	287	3.68	2.77	3.49	2.03	5.06	7.22	6.50	1832	
		288	3.38	2.74	3.45	2.02	2.97	5.39	6.48	1838	
		289	4.03	3.13	3.94	2.02	4.67	6.93	6.71	1775	
		473	3.66	3.31	4.17	2.29	4.97	7.09	6.94	1716	1222
Mean values			3.69	2.99	3.76	2.09			6.66	1790	1222
Standard deviation of the mean			±0.13	±0.14	±0.18	±0.06			±0.11	±29	
15.87	20	287	2.31	2.31	2.91	2.44	2.29	4.96	10.09	1573	1103
		288	2.36	1.91	2.41	2.14	3.75	6.33	10.31	1539	1034
		289	2.42	2.23	2.81	2.43	2.37	4.42	10.29	1542	1106
		473	2.48	2.41	3.04	2.57	3.14	4.42	9.88	1606	1347
Mean values			2.39	2.22	2.79	2.40			10.14	1565	1148
Standard deviation of the mean			±0.03	±0.11	±0.14	±0.09			±0.10	±16	±69

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TABLE 9

RESULTS OF AIR-BLAST MEASUREMENTS - 0.5-LB CHARGES

$D/W^{1/3}$ = 0.088; BOTTOM MATERIAL - SAND

CHARGE POSITION - AT BOTTOM (Z = -1.0D)

Gage Distance (ft)	Reduced Distance λ ($ft/lb^{1/3}$)	Shot No.*	Peak Pressure (psi)	Positive Impulse ($lb\text{-}ms/in^2$)	Reduced Positive Impulse ($lb\text{-}ms/in^2/lb^{1/3}$)	Positive Duration (ms)	Negative Impulse ($lb\text{-}ms/in^2$)	Negative Duration (ms)	Arrival Time (ms)	Avg Velocity Charge to Gage (ft/sec)	Avg Velocity Gage to Gage (ft/sec)
3.17	4	342	6.41	2.81	3.54	1.20	2.78	2.98	1.73	1832	
		342	6.37	2.82	3.55	0.97	13.33	4.67			
Mean values			6.39	2.82	3.55	1.09			1.73	1832	
Standard deviation of the mean			±0.02	0.00	0.00	±0.12			0.00	0	
4.76	6	279	4.17	1.83	2.31	1.17	5.03	3.52			
		279	4.42	2.14	2.70	0.93	7.62	5.31			
		280	4.32	2.12	2.67	1.14	3.96	4.34	2.70	1763	
		280	4.83	2.78	3.50	1.26	7.27	5.27	2.84	1676	
		342	5.19	2.62	3.30	1.42	6.35	4.78	2.92	1630	
		342	4.86	2.70	3.40	1.12	11.03	4.74	2.78	1712	1514
Mean values			4.63	2.37	2.98	1.17			2.81	1695	1514
Standard deviation of the mean			±0.16	±0.16	±0.21	±0.06			±0.05	±28	0
7.94	10	279	3.48	2.11	2.66	1.48	3.19	4.97			
		279	3.21	1.78	2.24	1.40	4.99	6.12			
		280	3.68	2.24	2.82	1.47	5.15	6.03	5.39	1473	1182
		280	3.78	2.17	2.73	1.41	5.33	5.75	5.56	1428	1169
		342	3.76	2.43	3.06	1.57	4.21	5.63	5.48	1449	1242
		342	3.53	2.41	3.04	1.64	7.78	7.60	5.52	1438	1161
Mean values			3.57	2.19	2.76	1.50			5.49	1447	1189
Standard deviation of the mean			±0.09	±0.10	±0.12	±0.03			±0.03	±10	±18
11.91	15	279	2.80	2.00	2.52	1.99	4.46	7.15	8.40	1418	
		280	2.58	1.89	2.38	1.80	2.48	6.20	8.36	1425	1378
		342	2.49	1.85	2.33	1.84	3.38	6.61	8.39	1420	1374
Mean values			2.62	1.91	2.41	1.88			8.38	1421	1376
Standard deviation of the mean			±0.09	±0.05	±0.06	±0.06			±0.01	±2	±2
15.87	20	279	1.92	1.42	1.79	1.89	1.68	5.67			
		280	2.00	1.56	1.97	1.93	2.25	6.30	11.96	1327	1100
		342	1.84	1.34	1.69	1.95	1.59	5.46	11.73	1353	1186
Mean values			1.92	1.44	1.82	1.92			11.85	1340	1143
Standard deviation of the mean			±0.04	±0.06	±0.11	±0.02			±0.11	±13	±43

*Shot number repeated where more than one gage used at a particular location.

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TABLE 10

RESULTS OF AIR-BLAST MEASUREMENTS - 0.5-LB CHARGES

$D/W^{1/3}$ = 0.088; BOTTOM MATERIAL - SAND

CHARGE POSITION - BELOW BOTTOM (Z = -2.5D)

Gage Distance (ft)	Reduced Distance λ ($ft/lb^{1/3}$)	Shot No.*	Peak Pressure (psi)	Positive Impulse ($lb\text{-}ms/in^2$)	Reduced Positive Impulse ($lb\text{-}ms/in^2/lb^{1/3}$)	Positive Duration (ms)	Negative Impulse ($lb\text{-}ms/in^2$)	Negative Duration (ms)	Arrival Time (ms)	Avg Velocity Charge to Gage (ft/sec)	Avg Velocity Gage to Gage (ft/sec)
4.76	6	281	3.56	1.99	2.51	1.23	5.35	5.24	3.22	1478	
		281	3.90	2.02	2.55	0.97	7.74	5.21	3.26	1460	
		282	3.83	2.05	2.58	1.07	5.32	5.17	3.32	1434	
		282	3.81	2.57	3.24	1.38	3.58	4.50	3.16	1506	
		283	4.17	2.28	2.87	1.15	2.74	3.99	3.22	1478	
		283	4.06	2.57	3.24	1.26	4.36	5.31	3.16	1506	
Mean values			3.89	2.25	2.83	1.18			3.22	1477	
Standard deviation of the mean			±0.09	±0.11	±0.14	±0.06			±0.02	±11	
7.94	10	281	2.70	1.49	1.88	1.46	3.36	5.40	5.86	1355	1205
		281	3.09	1.88	2.37	1.72	4.62	6.45	5.86	1355	1223
		282	3.13	1.65	2.08	1.45	4.38	6.27	5.89	1348	1237
		282	2.73	1.70	2.14	1.40	4.94	6.61	5.89	1348	1165
		283	2.95	2.32	2.92	1.65	4.30	5.83	5.85	1357	1182
		283	3.00	1.63	2.05	1.37	4.97	7.03	5.85	1357	1209
Mean values			2.93	1.78	2.24	1.51			5.87	1353	1204
Standard deviation of the mean			±0.07	±0.12	±0.15	±0.06			0.00	±2	±11
11.91	15	281	1.92	1.34	1.69	1.97	2.15	5.90	8.93	1334	1293
		282	2.05	1.35	1.70	1.91	1.64	5.43	8.91	1337	1315
		283	2.18	1.77	2.23	2.05	2.83	7.04	8.91	1337	1297
Mean values			2.05	1.49	1.87	1.84			8.92	1336	1302
Standard deviation of the mean			±0.08	±0.14	±0.18	±0.17			0.00	±1	±7
15.87	20	281	1.46	1.22	1.54	2.07	1.15	4.57	12.63	1257	1070
		282	1.58	1.17	1.47	1.95	3.06	8.61	12.65	1255	1059
		283	1.58	1.41	1.78	2.05	2.16	6.66	12.40	1280	1135
Mean values			1.54	1.27	1.60	2.02			12.56	1264	1088
Standard deviation of the mean			±0.05	±0.07	±0.10	±0.03			±0.08	±8	±26

*Shot number repeated where more than one gage used at a particular location.

TABLE 11

RESULTS OF AIR-BLAST MEASUREMENTS - 0.5-LB CHARGES

$D/W^{1/3}$ = 0.088; BOTTOM MATERIAL - SAND

CHARGE POSITION - BELOW BOTTOM (Z = -4.0D)

Gage Distance (ft)	Reduced Distance λ ($ft/lb^{1/3}$)	Shot No.*	Peak Pressure (psi)	Positive Impulse ($lb\text{-}ms/in^2$)	Reduced Positive Impulse ($lb\text{-}ms/in^2/lb^{1/3}$)	Positive Duration (ms)	Negative Impulse ($lb\text{-}ms/in^2$)	Negative Duration (ms)	Arrival Time (ms)	Avg Velocity Charge to Gage (ft/sec)	Avg Velocity Gage to Gage (ft/sec)
4.76	6	284	3.15	2.13	2.68	1.51	1.27	2.50	3.47	1372	
		284	3.91	2.36	2.97	1.44	8.16	4.87	3.42	1392	
		285	3.01	2.03	2.56	1.47	7.96	7.55	3.39	1404	
		285	3.48	2.29	2.89	1.58	7.30	5.38	3.41	1396	
		286	3.18	2.14	2.70	1.61	5.75	4.59	3.40	1400	
		286	3.23	1.81	2.28	1.31	7.18	4.85	3.44	1384	
Mean values			3.33	2.13	2.68	1.49			3.42	1391	
Standard deviation of the mean			±0.13	±0.08	±0.03	±0.05			±0.01	±5	
7.94	10	284	2.40	1.73	2.18	1.85	4.90	7.90	6.21	1279	1161
		284	2.56	1.62	2.04	1.74	5.78	7.31	6.13	1295	1173
		285	2.46	1.94	2.44	1.86	5.72	7.79	6.06	1310	1191
		285	2.33	1.52	1.92	1.91	4.11	6.60	6.20	1281	1140
		286	2.31	1.65	2.08	1.88	1.68	5.38	6.26	1268	1112
		286	2.28	1.66	2.09	1.58	4.85	6.75	6.41	1239	1071
Mean values			2.39	1.69	2.13	1.80			6.21	1279	1141
Standard deviation of the mean			±0.05	±0.06	±0.07	±0.06			±0.05	±10	±14
11.91	15	284	1.58	1.17	1.47	1.83	2.14	6.27	9.13	1304	1342
		285	1.52	1.28	1.61	1.98	2.81	7.19	9.19	1296	1296
		286	1.53	1.18	1.49	2.00	1.64	5.78	9.23	1290	1373
Mean values			1.54	1.21	1.52	1.94			9.18	1297	1337
Standard deviation of the mean			±0.02	±0.03	±0.05	±0.06			±0.03	±4	±22
15.87	20	284	1.32	1.14	1.44	2.17	1.33	5.37	12.32	1288	1241
		285	1.20	1.15	1.45	2.23	1.89	6.33	12.76	1244	1109
		286	1.17	1.04	1.31	2.37			12.85	1235	1094
Mean values			1.23	1.11	1.40	2.26			12.64	1256	1148
Standard deviation of the mean			±0.05	±0.03	±0.05	±0.06			±0.16	±16	±47

*Shot number repeated where more than one gage used at a particular location.

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TABLE 12

RESULTS OF AIR-BLAST MEASUREMENTS - 4-LB CHARGES

$D/W^{1/3}$ = 0.088; BOTTOM MATERIAL - SAND

CHARGE POSITION - ABOVE SURFACE (Z = 0.5D)

Gage Distance (ft)	Reduced Distance λ ($ft/lb^{1/3}$)	Shot No.*	Peak Pressure (psi)	Positive Impulse ($lb\text{-}ms/in^2$)	Reduced Positive Impulse ($lb\text{-}ms/in^2/lb^{1/3}$)	Positive Duration (ms)	Negative Impulse ($lb\text{-}ms/in^2$)	Negative Duration (ms)	Arrival Time (ms)	Avg Velocity Charge to Gage (ft/sec)	Avg Velocity Gage to Gage (ft/sec)
9.52	6	271	21.05								
		271	24.05								
		272	19.39								
		272	20.70								
		273	20.47	15.37	9.68	2.51	8.96	8.14	3.05	3121	
		273	18.50	14.52	9.15	2.37	29.83	14.74	3.05	3121	
Mean values			20.69	14.95	9.42	2.44			3.05	3121	
Standard deviation of the mean			±0.77	±0.42	±0.27	±0.07			0.00	0	
15.87	10	271	7.33	9.36	5.90	3.75	13.48	12.57	7.39	2147	
		271	8.47	9.74	6.14	3.33	16.65	12.67	7.37	2153	
		272	8.55	9.95	6.27	3.21	13.14	11.64	7.56	2099	
		272	8.06	8.46	5.33	3.48	12.97	13.77	7.56	2099	
		273	8.91	10.58	6.66	3.48	14.64	11.03	7.22	2198	1523
		273	8.21	10.23	6.44	3.52	13.97	13.27	7.21	2201	1526
Mean values			8.25	9.72	6.12	3.46			7.39	2150	1525
Standard deviation of the mean			±0.22	±0.30	±0.19	±0.08			±0.06	±18	±2
23.81	15	271	4.53	7.86	4.95	4.88	10.99	14.32	13.22	1801	1360
		272	4.34	7.03	4.43	4.38	7.72	11.75	13.53	1760	1330
		273	4.59	6.87	4.33	4.10	12.71	19.06	13.51	1762	1261
Mean values			4.49	7.25	4.57	4.45			13.42	1774	1317
Standard deviation of the mean			±0.07	±0.30	±0.19	±0.23			±0.10	±13	±29
31.75	20	271	2.89	6.24	3.93	5.38	8.66	16.44	20.08	1581	1157
		272	2.75	6.08	3.83	6.10	4.38	10.28	20.24	1569	1183
		273	2.89	6.29	3.96	5.43	5.12	10.51	19.87	1598	1248
Mean values			2.84	6.20	3.91	5.64			20.06	1583	1196
Standard deviation of the mean			±0.05	±0.06	±0.05	±0.23			±0.10	±8	±27

*Shot number repeated where more than one gage used at a particular location.

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TABLE 13

RESULTS OF AIR-BLAST MEASUREMENTS - 4-LB CHARGES

$D/W^{1/3}$ = 0.083; BOTTOM MATERIAL - SAND

CHARGE POSITION - AT SURFACE (Z = 0)

Gage Distance (ft)	Reduced Distance λ (ft/lb$^{1/3}$)	Shot No.*	Peak Pressure (psi)	Positive Impulse (lb-ms/in^2)	Reduced Positive Impulse (lb-ms/in^2/lb$^{1/3}$)	Positive Duration (ms)	Negative Impulse (lb-ms/in^2)	Negative Duration (ms)	Arrival Time (ms)	Avg Velocity Charge to Gage (ft/sec)	Avg Velocity Gage to Gage (ft/sec)
9.52	6	261	16.25	12.62	7.95	2.34			3.29	2894	
		261	16.04	12.74	8.03	2.39			3.36	2833	
		262	17.99	14.89	9.38	2.43	24.04	10.43	3.37	2825	
		262	17.73	14.37	9.05	2.36	15.81	10.35	3.26	2920	
		263	17.87				47.98	14.01	3.52	2705	
		263	18.03	12.77	8.04	2.31	12.59	9.89	3.36	2833	
Mean values			17.32	13.48	8.49	2.37			3.36	2835	
Standard deviation of the mean			±0.37	±0.48	±0.30	±0.02			±0.03	±30	
15.87	10	261	6.90								
		261	7.51								
		262	7.51	9.62	6.06	3.56	13.89	14.54	7.36	2156	1591
		262	8.65	10.31	6.49	3.37	17.17	14.31	7.41	2142	1530
		263	7.71	9.35	5.89	3.42	12.13	12.84	7.65	2075	1538
		263	8.06	9.21	5.80	3.45	16.09	13.55	7.75	2048	1446
Mean values			7.72	9.62	6.06	3.45			7.54	2105	1526
Standard deviation of the mean			±0.24	±0.25	±0.16	±0.05			±0.10	±24	±30
23.81	15	261	3.77	5.94	3.74	3.97	11.62	16.26	13.84	1720	
		262	4.25	6.52	4.11	4.36	7.66	12.59	13.22	1801	1361
		263	4.35	6.92	4.36	4.38	10.54	15.46	13.95	1707	1271
Mean values			4.12	6.46	4.07	4.24			13.67	1743	1316
Standard deviation of the mean			±0.18	±0.29	±0.18	±0.13			±0.21	±29	±45
31.75	20	261	2.73	5.04	3.18	5.12	6.17	10.75	20.34	1561	1222
		263	2.80	6.16	3.88	5.68	5.16	10.02	20.06	1583	1300
Mean values			2.77	5.60	3.53	5.40			20.20	1572	1261
Standard deviation of the mean			±0.03	±0.56	±0.35	±0.28			±0.14	±11	±39

*Shot number repeated where more than one gage used at a particular location.

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TABLE 14

RESULTS OF AIR-BLAST MEASUREMENTS - 4-LB CHARGES

$D/W^{1/3}$ = 0.088; BOTTOM MATERIAL - SAND

CHARGE POSITION - AT BOTTOM (Z = -1.0D)

Gage Distance (ft)	Reduced Distance λ ($ft/lb^{1/3}$)	Shot No.*	Peak Pressure (psi)	Positive Impulse ($lb\text{-}ms/in^2$)	Reduced Positive Impulse ($lb\text{-}ms/in^2/lb^{1/3}$)	Positive Duration (ms)	Negative Impulse ($lb\text{-}ms/in^2$)	Negative Duration (ms)	Arrival Time (ms)	Avg Velocity Charge to Gage (ft/sec)	Avg Velocity Gage to Gage (ft/sec)
9.52	6	255	12.30	10.59	6.67	2.22	12.01	7.49	3.99	2386	
		255	11.72	10.98	6.92	2.50	8.84	6.59	4.17	2283	
		343	**	9.38	5.91	2.36	15.56	11.58	4.59	2074	
		343	**	8.92	5.62	2.34	20.20	12.74	4.91	1939	
		444	9.31	7.26	4.57	2.00	15.75	9.45	4.95	1923	
		444	10.31	9.35	5.89	2.35	19.71	10.32	4.82	1975	
		470	**	9.86	6.21	2.38	13.58	10.39	4.26	2235	
		470	**	10.04	6.32	2.17	17.19	11.08	3.99	2386	
Mean values			10.91	9.55	6.01	2.29			4.46	2150	
Standard deviation of the mean			±0.68	±0.40	±0.26	±0.05			±0.14	±69	
15.87	10	255	6.60	8.18	5.15	3.25	23.67	12.78	8.47	1874	1417
		255	5.93	7.79	4.91	3.82	4.51	9.11	8.42	1885	1494
		343	7.48	5.82	3.67	2.83	18.58	13.20	9.95	1595	1185
		343	6.54	7.77	4.89	3.57	16.14	13.09	9.42	1685	1408
		444	5.88	6.50	4.09	2.73	15.26	9.75	9.65	1645	1351
		444	6.55	6.69	4.21	2.65	9.48	9.53	9.25	1716	1433
		470	7.19	8.77	5.52	3.48	5.93	9.43	8.89	1785	1371
		470	7.18	8.30	5.23	3.14	15.00	11.46	8.60	1845	1377
Mean values			6.67	7.48	4.71	3.18			9.08	1754	1380
Standard deviation of the mean			±0.21	±0.36	±0.22	±0.15			±0.20	±39	±32
23.81	15	255	3.38	4.58	2.89	3.53	6.48	14.37	14.46	1647	1321
		343	4.04	5.96	3.75	4.26	7.17	12.80	15.28	1558	1423
		444	3.88	5.14	3.24	3.23	6.72	10.51	15.21	1565	1332
		470	4.00	5.99	3.77	4.76	7.43	12.96	14.35	1659	1381
Mean values			3.83	5.42	3.41	3.95			14.83	1607	1364
Standard deviation of the mean			±0.15	±0.34	±0.21	±0.11			±0.24	±26	±23
31.75	20	255	2.73	5.54	3.49	5.23	8.23	18.03	20.74	1531	1264
		343	2.53	4.06	2.56	4.62	7.75	14.30	21.62	1469	1252
		444	2.86	3.63	2.29	3.69	8.45	15.54	20.98	1513	1029
		470	3.12	5.90	3.72	4.62	5.34	11.20	19.39	1637	1575
Mean values			2.81	4.78	3.02	4.54			20.68	1538	1280
Standard deviation of the mean			±0.12	±0.62	±0.35	±0.32			±0.47	±36	±112

*Shot number repeated where more than one gage used at a particular location.
**Multiple peak pressure on first positive phase.

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TABLE 15

RESULTS OF AIR-BLAST MEASUREMENTS - 4-LB CHARGES

$D/W^{1/3}$ = 0.088; BOTTOM MATERIAL - SAND

CHARGE POSITION - BELOW BOTTOM (Z = -2.5D)

Gage Distance (ft)	Reduced Distance λ ($ft/lb^{1/3}$)	Shot No.*	Peak Pressure (psi)	Positive Impulse ($lb\text{-}ms/in^2$)	Reduced Positive Impulse ($lb\text{-}ms/in^2/lb^{1/3}$)	Positive Duration (ms)	Negative Impulse ($lb\text{-}ms/in^2$)	Negative Duration (ms)	Arrival Time (ms)	Avg Velocity Charge to Gage (ft/sec)	Avg Velocity Gage to Gage (ft/sec)
9.52	6	264	6.89	6.04	3.80	2.37	13.15	10.37	6.25	1523	
		264	6.50	5.54	3.49	2.39	6.89	8.85	6.20	1535	
		265	7.15	6.12	3.86	2.12	10.25	9.79	5.38	1770	
		265	7.19	6.04	3.80	2.28	7.82	8.97	5.93	1605	
		266	7.46	5.52	3.48	2.18	8.88	8.14	5.84	1630	
Mean values			7.04	5.85	3.69	2.27			5.92	1613	
Standard deviation of the mean			±0.16	±0.14	±0.08	±0.06			±0.12	±44	
15.87	10	264	4.00	4.69	2.95	3.02	7.45	13.87	10.72	1480	1421
		264	4.21	4.87	3.07	2.89	2.44	6.67	11.00	1443	1323
		265	4.63	4.85	3.06	2.45	7.56	9.61	10.57	1501	1369
		266	4.48	3.94	2.48	2.96	8.49	12.04	11.04	1438	1221
		266	3.78	4.67	2.94	2.74	10.52	13.06	10.98	1445	1235
Mean values			4.22	4.60	2.90	2.81			10.86	1461	1314
Standard deviation of the mean			±0.16	±0.17	±0.11	±0.10			±0.10	±12	±34
23.81	15	264	2.82	3.61	2.27	3.58	2.58	10.04	17.56	1356	1186
		266	3.04	3.77	2.37	3.23	10.32	18.59	16.75	1421	1384
Mean values			2.93	3.69	2.32	3.41			17.16	1389	1285
Standard deviation of the mean			±0.11	±0.08	±0.05	±0.18			±0.41	±33	±99
31.75	20	264	2.24	3.19	2.01	4.38	9.97	18.96			
		266	2.25	3.45	2.17	4.40	3.13	9.65	23.49	1352	1178
Mean values			2.25	3.32	2.09	4.39			23.49	1352	1178
Standard deviation of the mean			±0.01	±0.13	±0.08	±0.01					

*Shot number repeated where more than one gage used at a particular location.

TABLE 16

RESULTS OF AIR-BLAST MEASUREMENTS - 4-LB CHARGES

$D/W^{1/3}$ = 0.088; BOTTOM MATERIAL - SAND

CHARGE POSITION - BELOW BOTTOM (Z = -4.0D)

Gage Distance (ft)	Reduced Distance λ ($ft/lb^{1/3}$)	Shot No.*	Peak Pressure (psi)	Positive Impulse ($lb\text{-}ms/in^2$)	Reduced Positive Impulse ($lb\text{-}ms/in^2/lb^{1/3}$)	Positive Duration (ms)	Negative Impulse ($lb\text{-}ms/in^2$)	Negative Duration (ms)	Arrival Time (ms)	Avg Velocity Charge to Gage (ft/sec)	Avg Velocity Gage to Gage (ft/sec)
9.52	6	267	4.11	5.23	3.29	2.96	10.61	9.66	6.87	1386	
		267	4.22	5.46	3.44	3.15					
		268	4.51	4.39	2.77	3.09	23.24	18.77	6.58	1447	
		269	3.94	4.20	2.65	2.96			6.72	1417	
		269	3.81	3.97	2.50	3.00	12.99	10.38	7.04	1352	
		274	3.31	6.16	3.88	3.88	11.04	9.94	7.00	1360	
		274	3.31	5.06	3.19	3.90	7.98	9.32	7.15	1331	
Mean values			3.89	4.92	3.10	3.28			6.89	1382	
Standard deviation of the mean			±0.17	±0.30	±0.18	±0.16			±0.09	±18	
15.87	10	267	2.61	3.85	2.43	3.74	5.66	11.35	11.97	1326	1245
		267	3.00	3.69	2.32	3.27	3.79	7.18	12.10	1312	1214
		268	2.86	3.23	2.03	3.52	7.58	13.39	11.58	1370	1270
		268	2.65	3.22	2.03	3.43	3.19	9.72	11.98	1325	1176
		269	2.73	3.91	2.46	3.99	6.89	13.28	12.21	1300	1157
		269	2.96	4.08	2.57	3.65	8.05	13.18	12.27	1293	1214
		274	2.43	3.25	2.05	3.88	8.01	13.18	12.44	1276	1167
		274	2.27	3.26	2.05	3.84	6.91	15.05	12.41	1279	1207
Mean values			2.69	3.56	2.24	3.67			12.12	1310	1206
Standard deviation of the mean			±0.08	±0.13	±0.08	±0.09			±0.09	±11	±14
23.81	15	267	1.62	2.67	1.68	4.20	5.73	11.94	18.54	1284	1221
		268	1.96	2.85	1.80	4.10	5.01	13.90	18.08	1317	1262
		269	1.84	2.60	1.64	3.89	6.90	18.59	18.97	1255	1180
		274	1.49	2.32	1.46	4.11	7.28	15.60	19.00	1253	1208
Mean values			1.73	2.61	1.65	4.08			18.65	1277	1218
Standard deviation of the mean			±0.11	±0.11	±0.07	±0.07			±0.22	±15	±17
31.75	20	267	1.39	2.39	1.51	4.59	4.71	14.77	24.59	1291	1312
		268	1.41	2.01	1.27	4.09	8.13	17.94	24.33	1305	1270
		269	1.46	3.07	1.93	5.25			25.56	1242	1205
		274	1.29	2.39	1.51	4.90	5.41	15.99	26.07	1218	1123
Mean values			1.39	2.47	1.56	4.71			25.14	1264	1228
Standard deviation of the mean			±0.03	±0.22	±0.14	±0.25			±0.41	±20	±41

*Shot number repeated where more than one gage used at a particular location.

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TABLE 17

RESULTS OF AIR-BLAST MEASUREMENTS - 16-LB CHARGES

$D/W^{1/3}$ = 0.088; BOTTOM MATERIAL - SAND

CHARGE POSITION - ABOVE SURFACE (Z = 0.5D)

Gage Distance (ft)	Reduced Distance λ ($ft/lb^{1/3}$)	Shot No.*	Peak Pressure (psi)	Positive Impulse ($lb\text{-}ms/in^2$)	Reduced Positive Impulse ($lb\text{-}ms/in^2/lb^{1/3}$)	Positive Duration (ms)	Negative Impulse ($lb\text{-}ms/in^2$)	Negative Duration (ms)	Arrival Time (ms)	Avg Velocity Charge to Gage (ft/sec)	Avg Velocity Gage to Gage (ft/sec)
10.08	4	326	73.88	47.13	18.70	2.36	116.21	13.21	1.05	9600	
		326	57.49	38.91	15.44	2.28	90.36	12.80	1.41	7149	
		329	52.27	39.75	15.78	2.77	64.55	11.67	1.22	8262	
Mean values			61.21	41.93	16.64	2.47			1.23	8337	
Standard deviation of the mean			±6.50	±2.62	±1.03	±0.15			±0.10	±709	
15.12	6	319	21.69	24.85	9.86	3.44	56.31	14.50	4.42	3421	
		319	18.14	31.30	12.42	4.39	8.64	5.61	4.65	3252	
		326	23.96	21.39	8.49	3.64	9.81	8.01	3.40	4447	2145
		326	16.90	21.50	8.53	3.61	53.70	17.56	3.50	4320	2411
		329	21.42	27.16	10.78	4.87	36.03	14.94	3.22	4696	2710
Mean values			20.42	25.24	10.02	3.99			3.84	4027	2422
Standard deviation of the mean			±1.27	±1.86	±0.74	±0.27			±0.31	±290	±163
25.20	10	319	8.51	17.38	6.90	5.56	25.29	19.48	11.36	2218	1452
		319	10.14	16.61	6.59	5.16	13.68	15.60	11.06	2278	1573
		326	**	16.93	6.72	8.21	19.32	18.68	9.63	2617	1618
		326	**	15.95	6.33	6.70	43.97	24.56	9.82	2566	1595
		329	7.35	14.58	5.79	6.47	22.26	22.18	10.24	2461	1450
		329	7.80	16.23	6.44	7.42	33.15	24.31	10.49	2402	1323
Mean values			8.45	16.28	6.46	6.59			10.43	2424	1502
Standard deviation of the mean			±0.61	±0.40	±0.16	±0.34			±0.28	±64	±46
37.80	15	319	4.14	11.89	4.72	6.80	12.23	26.67	20.82	1816	1312
		326	**	11.71	4.65	8.83	8.65	14.85	20.04	1886	1222
		329	3.49	10.84	4.30	7.16	7.81	13.39	19.77	1912	1340
Mean values			3.82	11.48	4.56	7.60			20.21	1871	1291
Standard deviation of the mean			±0.33	±0.32	±0.13	±0.63			±0.31	±29	±36
50.40	20	319	2.80	8.13	3.23	7.46	13.15	17.25	30.98	1627	1240
		326	**	8.38	3.33	8.58	16.94	26.07	30.35	1661	1222
		329	2.25	7.66	3.04	8.07	15.19	21.32	30.26	1666	1201
Mean values			2.53	8.06	3.20	8.04			30.53	1651	1221
Standard deviation of the mean			±0.28	±0.21	±0.08	±0.32			±0.23	±12	±11

*Shot number repeated where more than one gage used at a particular location.
**Multiple peak pressure on first positive phase.

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TABLE 18

RESULTS OF AIR-BLAST MEASUREMENTS - 16-LB CHARGES

$D/W^{1/3}$ = 0.088; BOTTOM MATERIAL - SAND

CHARGE POSITION - AT SURFACE (Z = 0)

Gage Distance (ft)	Reduced Distance λ ($ft/lb^{1/3}$)	Shot No.*	Peak Pressure (psi)	Positive Impulse ($lb\text{-}ms/in^2$)	Reduced Positive Impulse ($lb\text{-}ms/in^2/lb^{1/3}$)	Positive Duration (ms)	Negative Impulse ($lb\text{-}ms/in^2$)	Negative Duration (ms)	Arrival Time (ms)	Avg Velocity Charge to Gage (ft/sec)	Avg Velocity Gage to Gage (ft/sec)
10.08	4	325	28.15	23.54	9.34	2.76	56.00	13.44	2.25	4480	
		325	33.65	30.67	12.17	2.32	36.00	12.63	2.26	4460	
Mean values			30.90	27.11	10.75	2.54			2.25	4470	
Standard deviation of the mean			±2.75	±3.57	±1.42	±0.22			±0.01	±10	
15.12	6	314	22.23	34.51	13.70	3.37	74.51	14.71	4.49	3367	
		314	21.06	28.47	11.30	3.78	7.35	6.15	4.91	3079	
		315	12.56	20.73	8.23	4.01	26.45	14.71	5.30	2853	
		315	14.36	24.17	9.59	4.22	28.55	14.26	5.38	2810	
		325	16.24	21.39	8.49	3.70	36.78	15.39	5.06	2988	1794
		325	17.83	26.16	10.38	4.41	34.22	15.39	5.06	2988	1800
Mean values			17.38	25.91	10.28	3.92			5.03	3014	1797
Standard deviation of the mean			±1.55	±2.09	±0.83	±0.16			±0.13	±81	±3
25.20	10	314	8.75	17.05	6.77	5.09	34.06	22.47	11.60	2172	1418
		314	8.66	13.93	5.53	5.07					
		315	7.79	16.01	6.35	6.73	18.14	17.71	12.51	2014	1398
		315	8.11	15.34	6.09	6.61	35.76	20.49	12.93	1949	1335
		325	7.80	15.77	6.26	5.52	32.63	20.48	12.18	2069	1416
		325	8.43	17.62	6.99	6.28	23.19	17.96	12.33	2044	1387
Mean values			8.26	15.95	6.33	5.88			12.31	2050	1391
Standard deviation of the mean			±0.17	±0.53	±0.21	±0.31			±0.22	±37	±15
37.80	15	314	4.30	10.58	4.20	6.15			21.09	1792	1328
		315	3.94	11.83	4.69	7.20	7.54	13.56	22.48	1681	1291
		325	4.24	11.20	4.44	6.43	6.73	14.37	21.18	1785	1412
Mean values			4.16	11.20	4.44	6.59			21.58	1753	1344
Standard deviation of the mean			±0.11	±0.36	±0.14	±0.32			±0.45	±36	±36
50.40	20	314	2.83	10.94	4.34	9.83	9.60	20.93	31.44	1603	1217
		315	2.57	7.46	2.96	7.97	9.28	16.37	31.17	1617	1450
		325	2.92	7.87	3.12	6.65	10.58	15.30	31.93	1578	1172
Mean values			2.77	8.76	3.47	8.15			31.51	1599	1280
Standard deviation of the mean			±0.11	±1.10	±0.44	±0.92			±0.22	±11	±86

*Shot number repeated where more than one gage used at a particular location.

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TABLE 19

RESULTS OF AIR-BLAST MEASUREMENTS - 16-LB CHARGES

$D/W^{1/3}$ = 0.088; BOTTOM MATERIAL - SAND

CHARGE POSITION - AT BOTTOM (Z = -1.0D)

Gage Distance (ft)	Reduced Distance λ ($ft/lb^{1/3}$)	Shot No.*	Peak Pressure (psi)	Positive Impulse ($lb\text{-}ms/in^2$)	Reduced Positive Impulse ($lb\text{-}ms/in^2/lb^{1/3}$)	Positive Duration (ms)	Negative Impulse ($lb\text{-}ms/in^2$)	Negative Duration (ms)	Arrival Time (ms)	Avg Velocity Charge to Gage (ft/sec)	Avg Velocity Gage to Gage (ft/sec)
15.12	6	298	11.99	16.60	6.59	3.97	23.47	13.97	7.22	2094	
		298	11.98	16.15	6.41	4.17	26.56	18.31	7.15	2115	
		304	10.89	15.10	5.99	3.87	22.21	13.63	6.98	2166	
		304	9.69	14.00	5.56	4.14	31.21	13.96	6.83	2214	
		305	11.31	15.29	6.07	3.78	23.79	14.93	7.54	2005	
		305	10.87	15.94	6.33	4.56	30.45	14.83	7.56	2000	
Mean values			11.12	15.51	6.16	4.08			7.21	2099	
Standard deviation of the mean			±0.37	±0.46	±0.18	±0.11			±0.12	±35	
25.20	10	298	6.89	14.46	5.74	5.87	14.68	17.29	14.16	1780	1452
		298	6.97	13.09	5.19	4.88	32.24	19.31	14.53	1734	1366
		304	6.63	14.27	5.66	5.96	21.83	19.72	14.21	1773	1394
		304	6.59	11.52	4.57	5.08	38.70	20.36	13.97	1804	1412
		305	6.43	12.85	5.10	5.20	15.41	17.11	14.49	1739	1450
		305	6.66	13.65	5.42	6.17	29.39	18.70	14.48	1740	1457
Mean values			6.70	13.31	5.28	5.53			14.31	1762	1422
Standard deviation of the mean			±0.08	±0.44	±0.18	±0.22			±0.09	±12	±15
37.80	15	298	4.05	10.37	4.12	7.08	7.66	15.89	25.37	1490	1143
		305	3.99	9.08	3.60	6.07	10.70	17.63	24.56	1539	1251
Mean values			4.02	9.73	3.86	6.58			24.97	1515	1197
Standard deviation of the mean			±0.03	±0.65	±0.26	±0.51			±0.41	±25	±54
50.40	20	298	2.89	9.57	3.80	8.21	21.43	27.32	36.26	1390	1157
		305	2.77	7.91	3.14	7.11	13.03	19.93	35.12	1435	1193
Mean values			2.83	8.74	3.47	7.66			35.69	1413	1175
Standard deviation of the mean			±0.06	±0.83	±0.33	±0.55			±0.57	±23	±19

*Shot number repeated where more than one gage used at a particular location.

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TABLE 20

RESULTS OF AIR-BLAST MEASUREMENTS - 16-LB CHARGES

$D/W^{1/3}$ = 0.088; BOTTOM MATERIAL - SAND

CHARGE POSITION - BELOW BOTTOM (Z = -2.5D)

Gage Distance (ft)	Reduced Distance λ ($ft/lb^{1/3}$)	Shot No.*	Peak Pressure (psi)	Positive Impulse ($lb\text{-}ms/in^2$)	Reduced Positive Impulse ($lb\text{-}ms/in^2/lb^{1/3}$)	Positive Duration (ms)	Negative Impulse ($lb\text{-}ms/in^2$)	Negative Duration (ms)	Arrival Time (ms)	Avg Velocity Charge to Gage (ft/sec)	Avg Velocity Gage to Gage (ft/sec)
15.12	6	310	6.04	9.57	3.80	4.35	17.32	12.06	9.89	1529	
		310	5.86	9.07	3.60	4.13	14.38	12.27	10.03	1507	
		311	6.30	8.34	3.31	3.75	21.10	14.04	9.37	1614	
		311	6.15	9.01	3.58	3.73	15.33	13.65	9.30	1626	
		313	6.84	8.60	3.41	3.24	14.62	12.42	9.37	1614	
		313	6.92	9.01	3.58	3.43	18.26	14.16	9.06	1669	
Mean values			6.35	8.93	3.55	3.77			9.50	1593	
Standard deviation of the mean			±0.18	±0.17	±0.07	±0.17			±0.16	±25	
25.20	10	310	3.69	6.61	2.62	4.40	8.14	12.93	17.88	1409	1261
		310	3.92	5.68	2.25	4.04	27.93	20.43	17.68	1425	1317
		311	3.98	6.65	2.64	3.84	33.58	20.66	16.90	1491	1339
		311	4.00	7.01	2.78	4.63	25.21	21.19	17.24	1462	1270
		313	4.30	7.28	2.89	4.38	11.65	18.39	17.25	1461	1279
		313	4.34	7.27	2.89	4.67	11.31	16.83	17.30	1457	1260
Mean values			4.04	6.75	2.68	4.33			17.38	1451	1288
Standard deviation of the mean			±0.10	±0.15	±0.09	±0.13			±0.15	±12	±13
37.80	15	310	2.41	5.24	2.08	6.13	3.03	8.95	27.66	1367	1276
		311	2.35	5.14	2.04	5.33	8.19	18.25	26.91	1405	1281
		313	2.52	5.08	2.02	5.19	10.09	26.39	27.22	1389	1267
Mean values			2.43	5.15	2.05	5.55			27.26	1387	1275
Standard deviation of the mean			±0.05	±0.05	0.00	±0.29			±0.02	±11	±4
50.40	20	310	1.80	3.86	1.53	5.62	9.50	20.78	38.22	1319	1193
		311	1.86	4.97	1.97	6.38	6.60	18.05	37.23	1354	1113
		313	1.72	4.76	1.89	7.44			38.45	1311	1122
Mean values			1.79	4.53	1.80	6.48			37.97	1328	1143
Standard deviation of the mean			±0.04	±0.34	±0.13	±0.53			±0.38	±13	±25

*Shot number repeated where more than one gage used at a particular location.

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TABLE 21

RESULTS OF AIR-BLAST MEASUREMENTS - 16-LB CHARGES

$D/W^{1/3}$ = 0.088; BOTTOM MATERIAL - SAND

CHARGE POSITION - ABOVE SURFACE (Z = -4.0D)

Gage Distance (ft)	Reduced Distance λ ($ft/lb^{1/3}$)	Shot No.*	Peak Pressure (psi)	Positive Impulse ($lb\text{-}ms/in^2$)	Reduced Positive Impulse ($lb\text{-}ms/in^2/lb^{1/3}$)	Positive Duration (ms)	Negative Impulse ($lb\text{-}ms/in^2$)	Negative Duration (ms)	Arrival Time (ms)	Avg Velocity Charge to Gage (ft/sec)	Avg Velocity Gage to Gage (ft/sec)
15.12	6	307	4.49	7.31	2.90	4.61	16.97	13.20	11.04	1370	
		307	4.50	7.17	2.85	4.65			11.03	1371	
		308	4.14	6.79	2.69	4.29	19.95	14.56	10.96	1380	
		308	4.47	7.01	2.78	4.22	15.13	14.26	11.08	1365	
		309	4.72	7.61	3.02	4.11	23.07	14.24			
		309	4.74	7.65	3.04	4.13	28.65	21.58			
Mean values			4.51	7.26	2.88	4.34			11.03	1372	
Standard deviation of the mean			±0.09	±0.14	±0.06	±0.09			±0.03	±3	
25.20	10	307	3.03								
		307	3.11								
		308	2.52	4.96	1.97	5.45	12.46	21.08	18.32	1376	1370
		308	2.44	4.87	1.93	5.14			19.23	1310	1237
		309	2.83	5.09	2.02	4.38	28.27	21.40	19.89	1267	
		309	2.83	4.31	1.71	4.03	23.47	22.00	19.61	1285	
Mean values			2.79	4.81	1.91	4.75			19.26	1310	1304
Standard deviation of the mean			±0.11	±0.18	±0.07	±0.33			±0.34	±24	±67
37.80	15	307	1.89	4.87	1.93	7.22			29.25	1292	
		308	1.71	4.35	1.73	6.71	4.13	14.82	29.93	1263	1131
		309	1.87	4.23	1.68	6.92	11.66	23.37	29.18	1295	1336
Mean values			1.82	4.48	1.78	6.95			29.45	1283	1234
Standard deviation of the mean			±0.06	±0.20	±0.08	±0.15			±0.24	±10	±103
50.40	20	307	1.40	2.83	1.12	4.94	6.80	21.08	40.50	1244	1120
		308	1.28	3.10	1.23	6.04	10.12	25.69	42.50	1186	1002
		309	1.35	3.43	1.36	7.17	4.69	17.98	40.61	1241	1102
Mean values			1.34	3.12	1.24	6.05			41.20	1224	1075
Standard deviation of the mean			±0.03	±0.17	±0.07	±0.65			±0.65	±19	±37

*Shot number repeated where more than one gage used at a particular location.

TABLE 22

RESULTS OF AIR-BLAST MEASUREMENTS - 32-LB CHARGES

$D/W^{1/3}$ = 0.088; BOTTOM MATERIAL - SAND

CHARGE POSITION - AT BOTTOM (Z = -1.00)

Gage Distance (ft)	Reduced Distance λ ($ft/lb^{1/3}$)	Shot No.*	Peak Pressure (psi)	Positive Impulse ($lb\text{-}ms/in^2$)	Reduced Positive Impulse ($lb\text{-}ms/in^2/lb^{1/3}$)	Positive Duration (ms)	Negative Impulse ($lb\text{-}ms/in^2$)	Negative Duration (ms)	Arrival Time (ms)	Avg Velocity Charge to Gage (ft/sec)	Avg Velocity Gage to Gage (ft/sec)
12.70	4	330	13.32	18.35	5.78	3.10	33.70	12.42	4.98	2550	
		330	15.70	19.68	6.20	3.36	42.08	13.63	5.57	2280	
		337	16.84	21.61	6.81	3.11	18.35	8.81	4.75	2674	
		337	16.65	20.24	6.38	2.80	46.00	12.84	4.61	2755	
		338	14.52	20.70	6.52	3.48	18.41	11.22	5.17	2456	
		338	14.86	19.40	6.11	3.29	40.25	12.39	5.31	2392	
Mean values			15.32	20.00	6.30	3.19			5.07	2518	
Standard deviation of the mean			±0.55	±0.46	±0.15	±0.10			±0.15	±52	
19.05	6	330	12.29	18.70	5.89	4.33	30.11	19.04	9.08	2098	1549
		330	12.14	20.74	6.53	5.16	39.47	17.99	9.53	1999	1604
		337	13.27	22.33	7.03	4.90	35.50	18.35	8.86	2150	1545
		337	14.28	23.08	7.27	4.89	37.55	18.82	8.61	2213	1588
		338	12.54	19.14	6.03	4.60	33.53	18.09	9.59	1986	1437
		338	12.52	20.20	6.36	4.75	39.48	18.79	9.15	2082	1654
Mean values			12.84	20.70	6.52	4.77			9.14	2088	1563
Standard deviation of the mean			±0.33	±0.71	±0.23	±0.14			±0.16	±36	±30
31.75	10	330	7.13	16.52	5.20	6.82	18.97	20.91	19.01	1670	1279
		330	7.06	14.35	4.52	6.76	41.60	24.17	18.44	1722	1425
		337	7.23	18.04	5.68	6.60	16.03	19.51	17.85	1779	1413
		337	7.33	14.48	4.56	6.03	19.37	16.83	17.38	1827	1448
		338	7.06	16.26	5.12	6.79	20.19	20.75	18.36	1729	1448
		338	7.33	13.61	4.29	6.38	27.89	22.75	19.04	1668	1344
Mean values			7.19	15.54	4.90	6.56			18.35	1733	1393
Standard deviation of the mean			±0.06	±0.68	±0.22	±0.12			±0.27	±25	±28
47.62	15	330	3.92	12.69	4.00	8.41	23.92	34.64	31.47	1513	1246
		337	3.87	11.43	3.60	7.24	7.27	17.55	29.51	1614	1333
		338	4.20	11.78	3.71	7.57	14.94	29.40	29.84	1996	1425
Mean values			4.00	11.97	3.77	7.74			30.27	1574	1335
Standard deviation of the mean			±0.10	±0.38	±0.12	±0.35			±0.61	±31	±52
63.50	20	330	2.61	9.10	2.87	9.13	9.78	24.22	43.11	1473	1364
		337	2.46	7.45	2.35	7.40	15.32	27.86	42.50	1494	1222
		338	2.47	7.79	2.45	8.12	8.93	19.87	42.50	1494	1254
Mean values			2.51	8.11	2.56	8.22			42.70	1487	1280
Standard deviation of the mean			±0.05	±0.50	±0.16	±0.50			±0.20	±7	±43

*Shot number repeated where more than one gage used at a particular location.

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TABLE 23

RESULTS OF AIR-BLAST MEASUREMENTS - 32-LB CHARGES

$D/W^{1/3}$ = 0.088; BOTTOM MATERIAL - SAND

CHARGE POSITION - BELOW BOTTOM (Z = -2.5D)

Gage Distance (ft)	Reduced Distance λ ($ft/lb^{1/3}$)	Shot No.*	Peak Pressure (psi)	Positive Impulse ($lb\text{-}ms/in^2$)	Reduced Positive Impulse ($lb\text{-}ms/in^2/lb^{1/3}$)	Positive Duration (ms)	Negative Impulse ($lb\text{-}ms/in^2$)	Negative Duration (ms)	Arrival Time (ms)	Avg Velocity Charge to Gage (ft/ms)	Avg Velocity Gage to Gage (ft/ms)
12.70	4	331	7.95				50.00	13.45	7.33	1733	
		331	8.28	12.61	3.97	3.33			7.51	1691	
		332	8.41	14.07	4.43	4.33	29.46	13.69			
		332	8.43	11.59	3.65	3.69	62.31	25.03	7.42	1712	
		336	10.47	13.67	4.31	3.68	28.33	11.76	6.85	1854	
		336	10.52	12.88	4.06	3.77	31.46	11.84	6.97	1822	
Mean values			9.01	12.96	4.08	3.76			7.22	1762	
Standard deviation of the mean			±0.48	±0.44	±0.14	±0.16			±0.13	±32	
19.05	6	331	6.03	9.78	3.08	4.69	38.06	18.88	12.34	1544	1267
		331	6.37	12.17	3.83	5.97	12.95	13.71	12.31	1548	1323
		332	6.14	9.59	3.02	4.26	24.32	20.46	12.07	1578	1366
		332	5.88	9.88	3.11	4.92	20.79	18.45	11.98	1590	1393
		336	7.78	12.76	4.02	4.41	16.67	17.64	11.53	1652	1357
		336	8.51	13.31	4.19	4.57	25.69	17.59	11.53	1652	1393
Mean values			6.79	11.25	3.54	4.80			11.96	1594	1350
Standard deviation of the mean			±0.45	±0.69	±0.22	±0.25			±0.15	±20	±20
31.75	10	331	3.86	9.43	2.97	5.71	20.07	25.09	21.90	1450	1328
		331	3.92	10.45	3.29	6.92	23.03	25.05	22.17	1432	1288
		332	4.16	9.20	2.90	5.83	18.81	23.95	22.33	1422	1238
		332	4.02	8.45	2.66	5.40	11.70	18.70	21.90	1450	1280
		336	5.21	10.83	3.41	5.48	25.16	23.56	21.52	1475	1271
		336	5.29	10.78	3.40	5.91	18.03	22.31	21.76	1459	1241
Mean values			4.41	9.86	3.11	5.88			21.93	1448	1274
Standard deviation of the mean			±0.27	±0.40	±0.13	±0.23			±0.12	±8	±14
47.62	15	331	2.77	7.79	2.45	7.63			35.00	1361	1224
		332	2.99	7.81	2.46	6.85			34.24	1391	1309
		336	3.42	8.90	2.80	6.93	2.81	6.69	34.43	1383	1241
Mean values			3.06	8.17	2.57	7.14			34.56	1378	1258
Standard deviation of the mean			±0.19	±0.37	±0.12	±0.26			±0.23	±9	±26
63.50	20	331	1.97	5.46	1.72	7.84	8.99	22.96	47.38	1340	1283
		332	2.01	5.77	1.82	7.02	5.48	15.07	47.50	1337	1198
		336	2.04	6.73	2.12	7.96	11.41	24.60	48.72	1303	1111
Mean values			2.01	5.99	1.89	7.61			47.87	1327	1197
Standard deviation of the mean			±0.02	±0.38	±0.37	±0.30			±0.43	±12	±50

*Shot number repeated where more than one gage used at a particular location.

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TABLE 24

RESULTS OF AIR-BLAST MEASUREMENTS - 32-LB CHARGES

$D/W^{1/3}$ = 0.088; BOTTOM MATERIAL - SAND

CHARGE POSITION - BELOW BOTTOM (Z = -4.0D)

Gage Distance (ft)	Reduced Distance λ ($ft/lb^{1/3}$)	Shot No.*	Peak Pressure (psi)	Positive Impulse ($lb\text{-}ms/in^2$)	Reduced Positive Impulse ($lb\text{-}ms/in^2/lb^{1/3}$)	Positive Duration (ms)	Negative Impulse ($lb\text{-}ms/in^2$)	Negative Duration (ms)	Arrival Time (ms)	Avg Velocity Charge to Gage (ft/sec)	Avg Velocity Gage to Gage (ft/sec)
12.70	4	333	3.69	11.84	3.73	8.15	26.31	14.06	8.43	1507	
		334	3.85	11.23	3.54	5.68			8.49	1496	
		334	4.02	10.25	3.23	5.68			8.89	1429	
Mean values			3.85	11.11	3.50	6.50			8.60	1477	
Standard deviation of the mean			±0.10	±0.46	±0.15	±0.82			±0.15	±24	
19.05	6	323	2.89	13.82	4.35	7.35			14.93	1278	
		323	3.20	12.24	3.86	7.83			14.81	1288	
		333	3.01	8.94	2.82	7.53			14.08	1353	1124
		333	3.46	9.83	3.10	9.25	24.02	21.49	13.66	1394	1214
		334	3.22	9.06	2.85	8.13	11.56	19.31			
		334	3.69	9.03	2.84	7.11	23.06	20.01	13.86	1374	1278
Mean values			3.25	10.49	3.30	7.87			14.27	1337	1205
Standard deviation of the mean			±0.12	±0.84	±0.27	±0.31			±0.26	±23	±45
31.75	10	323	2.43	7.65	2.41	7.73			25.70	1235	1176
		323	2.60	8.46	2.66	9.26	12.83	14.87	25.63	1239	1171
		333	2.55	7.07	2.23	7.29	5.86	13.43	24.63	1289	1204
		333	2.69	7.84	2.47	8.56	12.77	17.16	24.52	1295	1169
		334	2.44	7.74	2.44	7.62	15.26	23.30	24.57	1292	1261
		334	2.51	6.47	2.04	6.71	7.48	15.07	25.05	1267	1135
Mean values			2.54	7.54	2.38	7.86			25.02	1270	1186
Standard deviation of the mean			±0.04	±0.20	±0.09	±0.37			±0.24	±11	±18
47.62	15	323	1.57	4.54	1.43	7.75	5.19	13.52	38.94	1223	1196
		333	1.70	5.42	1.71	8.08	6.52	19.37	38.25	1245	1160
		334	1.76	5.29	1.67	8.69	10.13	30.45	38.26	1245	1180
Mean values			1.68	5.08	1.60	8.17			38.48	1238	1179
Standard deviation of the mean			±0.06	±0.25	±0.09	±0.32			±0.23	±7	±10
63.50	20	323	1.19	4.17	1.31	7.83	10.96	26.43	52.85	1202	1142
		333	1.24	4.16	1.31	8.36	5.31	18.93	52.50	1210	1114
		334	1.21	4.32	1.36	9.57	3.86	13.27			
Mean values			1.21	4.22	1.33	8.59			52.68	1206	1128
Standard deviation of the mean			±0.01	±0.05	±0.02	±0.51			±0.18	±4	±16

*Shot number repeated where more than one gage used at a particular location.

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TABLE 25

RESULTS OF AIR-BLAST MEASUREMENTS - FIELD TESTS - 32-LB CHARGES

$D/W^{1/3}$ = 0.088; BOTTOM MATERIAL - SAND

CHARGE POSITION - ABOVE SURFACE (Z = 0.5D)

Gage Distance (ft)	Reduced Distance λ $(ft/lb^{1/3})$	Shot No.*	Peak Pressure (psi)	Positive Impulse $(lb\text{-}ms/in^2)$	Reduced Positive Impulse $(lb\text{-}ms/in^2/lb^{1/3})$	Positive Duration (ms)	Negative Impulse $(lb\text{-}ms/in^2)$	Negative Duration (ms)	Arrival Time (ms)	Avg Velocity Charge to Gage (ft/sec)	Avg Velocity Gage to Gage (ft/sec)
19.05	6	431	19.92	31.93	10.06	4.33	14.96	12.80	5.19	3671	
		431	20.43	28.30	8.91	4.02	26.13	19.14	5.22	3649	
		440	18.70	27.70	8.72	4.31	41.62	20.35	5.59	3408	
		441	22.81	30.97	9.75	4.00	79.31	30.51	4.79	3977	
Mean values			20.47	29.73	9.36	4.17			5.20	3676	
Standard deviation of the mean			±0.77	±1.02	±1.02	±0.09			±0.05	±117	
31.75	10	431	7.99	19.60	6.17	6.71	27.18	25.40	12.48	2544	1746
		440	8.24	19.76	6.22	7.13	22.68	19.97	13.37	2375	1632
		441	7.66	17.74	5.59	5.93	32.47	18.52	13.58	2338	1445
		441	8.35	20.63	6.50	6.39	23.78	21.16	12.87	2467	1572
Mean values			8.06	19.43	6.12	6.54			13.08	2431	1599
Standard deviation of the mean			±0.15	±0.61	±0.19	±0.25			±0.25	±46	±63
47.62	15	440	4.25	14.38	4.53	8.50	26.06	32.72	24.24	1965	1460
		441	4.04	13.54	4.26	8.84	15.65	24.88	24.95	1909	1355
Mean values			4.15	13.96	4.40	8.67			24.60	1937	1408
Standard deviation of the mean			±0.11	±0.42	±0.14	±0.17			±0.36	±28	±53
63.50	20	431	2.54	9.00	2.83	8.12	16.84	26.00	36.42	1744	
		440	2.91	10.27	3.23	9.24	20.75	27.79	37.50	1693	1198
		441	2.88	10.59	3.34	9.29	16.44	24.90	36.63	1734	1360
Mean values			2.78	9.95	3.13	8.88			36.85	1724	1279
Standard deviation of the mean			±0.12	±0.49	±0.49	±0.38			±0.33	±13	±81

*Shot number repeated where more than one gage used at a particular location.

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TABLE 26

RESULTS OF AIR-BLAST MEASUREMENTS - FIELD TESTS - 32-LB CHARGES

$D/W^{1/3}$ = 0.088; BOTTOM MATERIAL - SAND

CHARGE POSITION - AT SURFACE (Z = 0)

Gage Distance (ft)	Reduced Distance λ ($ft/lb^{1/3}$)	Shot No.*	Peak Pressure (psi)	Positive Impulse ($lb\text{-}ms/in^2$)	Reduced Positive Impulse ($lb\text{-}ms/in^2/lb^{1/3}$)	Positive Duration (ms)	Negative Impulse ($lb\text{-}ms/in^2$)	Negative Duration (ms)	Arrival Time (ms)	Avg Velocity Charge to Gage (ft/sec)	Avg Velocity Gage to Gage (ft/sec)
19.05	6	432	14.97	17.21	5.42	3.78	21.46	13.30	7.06	2698	
		432	15.03	19.85	6.25	3.92	31.21	17.08	7.28	2617	
		438	17.22	26.30	8.28	4.94	29.86	17.34	5.97	3245	
		438	17.03	25.29	7.97	4.85	35.74	16.48	6.12	3113	
		439	15.85	24.38	7.68	4.62	19.18	13.33	6.58	2895	
Mean values			16.02	22.61	7.12	4.40			6.58	2914	
Standard deviation of the mean			±0.48	±1.74	±0.55	±0.25			±0.27	±119	
31.75	10	432	6.79	17.43	5.49	6.52	19.57	21.06	15.89	1998	1457
		438	7.62	18.28	5.76	6.43	20.47	17.34	15.01	2115	1389
		438	7.94	19.37	6.10	6.14	17.95	17.18	14.65	2167	1489
		439	7.07	17.67	5.57	6.27	24.19	19.68	15.91	1996	1361
		439	7.19	17.05	5.37	6.15	19.32	16.71	15.08	2105	1494
Mean values			7.32	17.96	5.66	6.30			15.31	2076	1438
Standard deviation of the mean			±0.20	±0.41	±0.13	±0.08			±0.25	±34	±27
47.62	15	432	3.79	11.64	3.67	7.71	7.50	14.82	26.90	1770	1441
		438	3.69	14.15	4.46	9.75	16.54	23.69	26.98	1772	1318
Mean values			3.74	12.90	4.07	8.73			26.89	1771	1380
Standard deviation of the mean			±0.05	±1.25	±0.40	±1.02			±0.01	±1	±62
63.50	20	432	2.77	9.85	3.10	8.76	13.10	21.63	39.72	1599	1239
		438	2.79	10.77	3.39	9.23	14.95	24.15	37.13	1710	
		439	2.92	10.30	3.24	8.96	15.63	24.88	38.19	1663	
Mean values			2.83	10.31	3.24	8.98			38.35	1657	1239
Standard deviation of the mean			±0.15	±0.27	±0.08	±0.14			±0.75	±32	

*Shot number repeated where more than one gage used at a particular location.

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TABLE 27

RESULTS OF AIR-BLAST MEASUREMENTS - FIELD TESTS - 256-LB CHARGES

$D/W^{1/3}$ = 0.088; BOTTOM MATERIAL - SAND

CHARGE POSITION - AT BOTTOM (Z = -1.00)

Gage Distance (ft)	Reduced Distance λ (ft/lb$^{1/3}$)	Shot No.*	Peak Pressure (psi)	Positive Impulse (lb-ms/in^2)	Reduced Positive Impulse (lb-ms/in^2/lb$^{1/3}$)	Positive Duration (ms)	Negative Impulse (lb-ms/in^2)	Negative Duration (ms)	Arrival Time (ms)	Avg Velocity Charge to Gage (ft/sec)	Avg Velocity Gage to Gage (ft/sec)
38.10	6	421	12.35	33.67	5.30	7.19	94.05	37.40	17.66	2157	
		421	12.73	36.39	5.73	8.47	52.68	22.92	17.19	2216	
		423	11.57	25.85	4.07	5.93	62.68	18.89	17.50	2177	
Mean values			12.22	31.97	5.03	7.20			17.45	2183	
Standard deviation of the mean			±0.11	±3.23	±0.50	±0.73			±0.14	±17	
63.50	10	421	7.65	28.99	4.57	9.16	62.61	28.01	36.02	1763	1366
		423	7.89	25.97	4.09	10.30	44.16	37.04	35.80	1774	1498
Mean values			7.77	27.48	4.33	9.73			35.91	1769	1432
Standard deviation of the mean			±0.12	±1.51	±0.24	±0.57			±0.11	±6	±66
95.24	15	421	5.16	25.63	4.04	16.52	24.08	26.76	59.76	1594	1337
126.99	20	421	3.01	19.32	3.04	16.37	15.42	27.18	86.45	1469	1190
		423	3.09	19.50	3.07	15.28	12.00	19.17			
Mean values			3.05	19.41	3.06	15.83			86.45	1469	1190
Standard deviation of the mean			±0.04	±0.09	±0.02	±0.55					

*Shot number repeated where more than one gage used at a particular location.

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TABLE 28

RESULTS OF AIR-BLAST MEASUREMENTS - FIELD TESTS - 256-LB CHARGES

$D/W^{1/3}$ = 0.088; BOTTOM MATERIAL - SAND

CHARGE POSITION - BELOW BOTTOM (Z = -2.5D)

Gage Distance (ft)	Reduced Distance λ ($ft/lb^{1/3}$)	Shot No.*	Peak Pressure (psi)	Positive Impulse ($lb\text{-}ms/in^2$)	Reduced Positive Impulse ($lb\text{-}ms/in^2/lb^{1/3}$)	Positive Duration (ms)	Negative Impulse ($lb\text{-}ms/in^2$)	Negative Duration (ms)	Arrival Time (ms)	Avg Velocity Charge to Gage (ft/sec)	Avg Velocity Gage to Gage (ft/sec)
38.10	6	426	6.49	17.16	2.70	7.59	47.89	31.08	22.56	1689	
		427	5.65	18.93	2.98	7.53			24.18	1576	
		427	5.64	20.22	3.18	7.82			24.40	1561	
Mean values			5.93	18.77	2.95	7.65			23.71	1609	
Standard deviation of the mean			±0.28	±0.79	±0.14	±0.09			±0.61	±40	
63.50	10	426	4.53	18.72	2.95	11.79	28.46	25.59	42.50	1494	1274
		426	3.69	15.69	2.47	11.31	26.17	40.39	42.50	1494	1274
		427	4.25	16.54	2.60	10.99	35.13	36.71	44.18	1437	1270
		427	3.69	15.77	2.48	12.22			43.50	1460	1330
Mean values			4.04	16.68	2.63	11.58			43.17	1471	1287
Standard deviation of the mean			±0.21	±0.70	±0.11	±0.27			±0.41	±14	±14
95.24	15	426	2.71	13.02	2.05	12.72	25.34	44.49	67.25	1416	1282
126.99	20	427	1.93	10.99	1.73	15.07	10.62	26.29	95.00	1337	

*Shot number repeated where more than one gage used at a particular location.

TABLE 29

RESULTS OF AIR-BLAST MEASUREMENTS - FIELD TESTS - 256-LB CHARGES

$D/W^{1/3}$ = 0.088; BOTTOM MATERIAL - SAND

CHARGE POSITION - BELOW BOTTOM (Z = -4.00)

Gage Distance (ft)	Reduced Distance λ (ft/lb1/3)	Shot No.*	Peak Pressure (psi)	Positive Impulse (lb-ms/in^2)	Reduced Positive Impulse (lb-ms/in^2/lb$^{1/3}$)	Positive Duration (ms)	Negative Impulse (lb-ms/in^2)	Negative Duration (ms)	Arrival Time (ms)	Avg Velocity Charge to Gage (ft/sec)	Avg Velocity Gage to Gage (ft/sec)
38.10	6	428	5.85	20.16	3.18	13.56	27.21	33.25	26.46	1440	
		428	4.63	24.89	3.92	16.22	38.30	34.39	27.38	1392	
		429	3.03	12.27	1.93	9.98			26.80	1422	
		429	3.00	15.70	2.47	12.82			25.50	1494	
Mean values			3.93	18.26	2.88	13.15			26.54	1437	
Standard deviation of the mean			±0.53	±2.74	±0.43	±1.29			±0.39	±21	
63.50	10	428	2.99	17.19	2.71	15.61			46.65	1361	1311
95.24	15	428	1.84	9.73	1.53	14.31			71.53	1331	1236
		429	1.46	7.97	1.26	15.99	25.85	44.93	70.00	1361	
Mean values			1.65	8.85	1.40	15.15			70.77	1346	1236
Standard deviation of the mean			±0.19	±0.88	±0.14	±0.84			±0.77	±15	
126.99	20	428	1.25	6.58	1.04	10.62			97.50	1302	1223
		429	1.20	8.15	1.28	17.29	10.62	40.42	101.00	1257	1024
Mean values			1.23	7.37	1.16	13.96			99.25	1280	1124
Standard deviation of the mean			±0.03	±0.79	±0.12	±3.34			±1.75	±23	±100

*Shot number repeated where more than one gage used at a particular location.

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TABLE 30

RESULTS OF AIR-BLAST MEASUREMENTS - FIELD TESTS - 2048-LB CHARGE

$D/W^{1/3}$ = 0.088; BOTTOM MATERIAL - SAND

CHARGE POSITION - AT BOTTOM (Z = -1.0D)

Gage Distance (ft)	Reduced Distance λ (ft/lb1/3)	Shot No.*	Peak Pressure (psi)	Positive Impulse (lb-ms/in^2)	Reduced Positive Impulse (lb-ms/in^2/lb1/3)	Positive Duration (ms)	Negative Impulse (lb-ms/in^2)	Negative Duration (ms)	Arrival Time (ms)	Avg Velocity Charge to Gage (ft/sec)	Avg Velocity Gage to Gage (ft/sec)
76.20	6	422	10.69	62.43	4.92	16.00	87.84	45.25	36.70	2076	
		422	11.82	54.50	4.29	9.70	99.00	28.25	37.50	2032	
Mean values			11.26	58.47	4.61	12.85			37.10	2054	
Standard deviation of the mean			±0.57	±3.97	±0.32	±3.15			±0.40	±22	
126.99	10	422	7.33								
		422	6.51								
Mean values			6.92								
Standard deviation of the mean			±0.41								
190.49	15	422	4.28	45.90	3.61	30.00	8.03	23.22	120.00	1587	
253.98	20	422	3.05	33.54	2.64	31.00	87.20	76.76	172.00	1477	1221

*Shot number repeated where more than one gage used at a particular location.

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PLATES

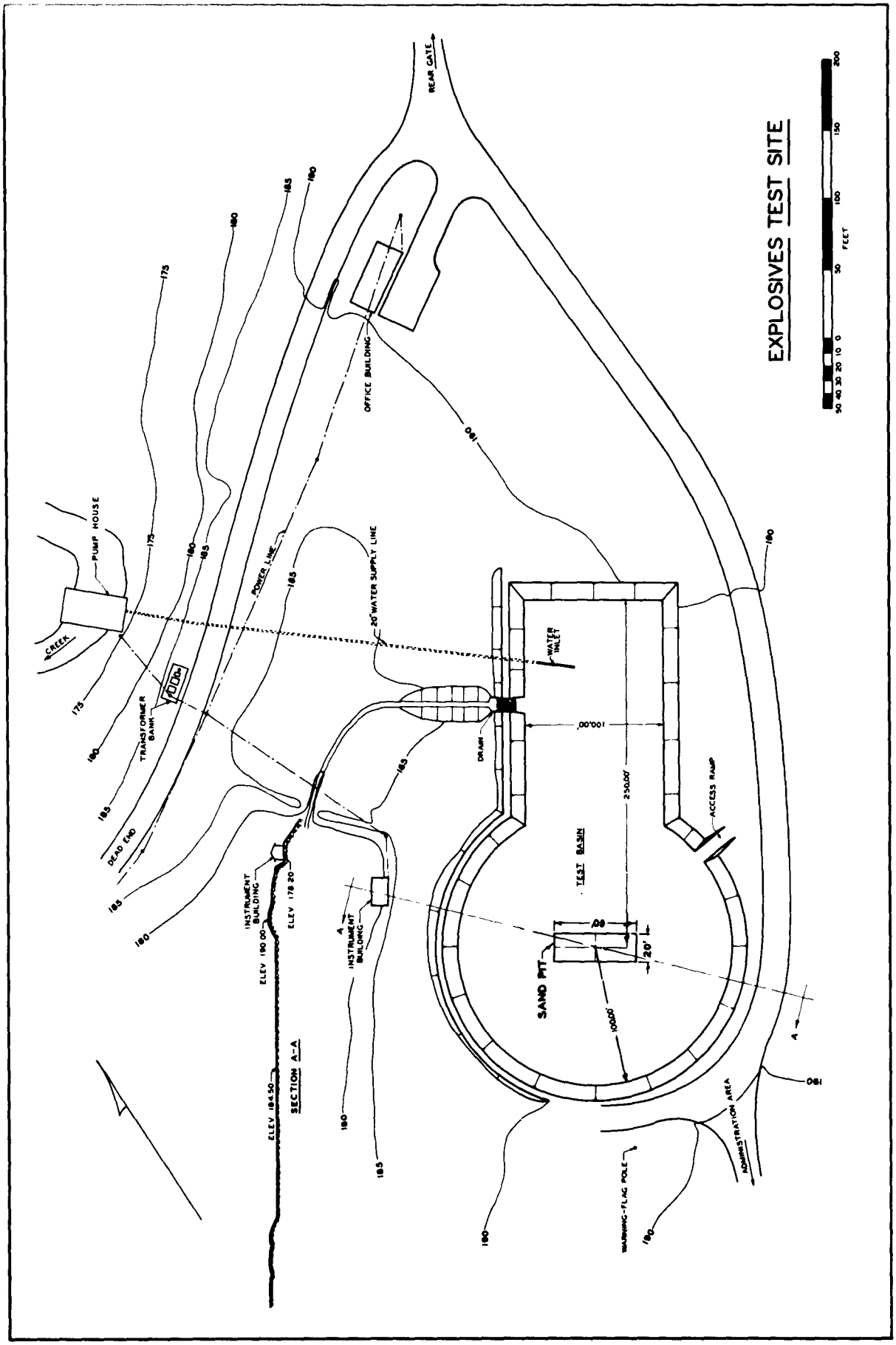

EXPLOSIVES TEST SITE
REAR GATE
OFFICE BUILDING
PUMP HOUSE
CREEK
TRANSFORMER BANK
POWER LINE
20" WATER SUPPLY LINE
WATER INLET
DRAIN
DEAD END
INSTRUMENT BUILDING
ELEV 178 20
ELEV 180 00
ELEV 184 50
SECTION A-A
TEST BASIN
SAND PIT
ACCESS RAMP
WARNING-FLAG POLE
ADMINISTRATION AREA
FEET

PLATE 1

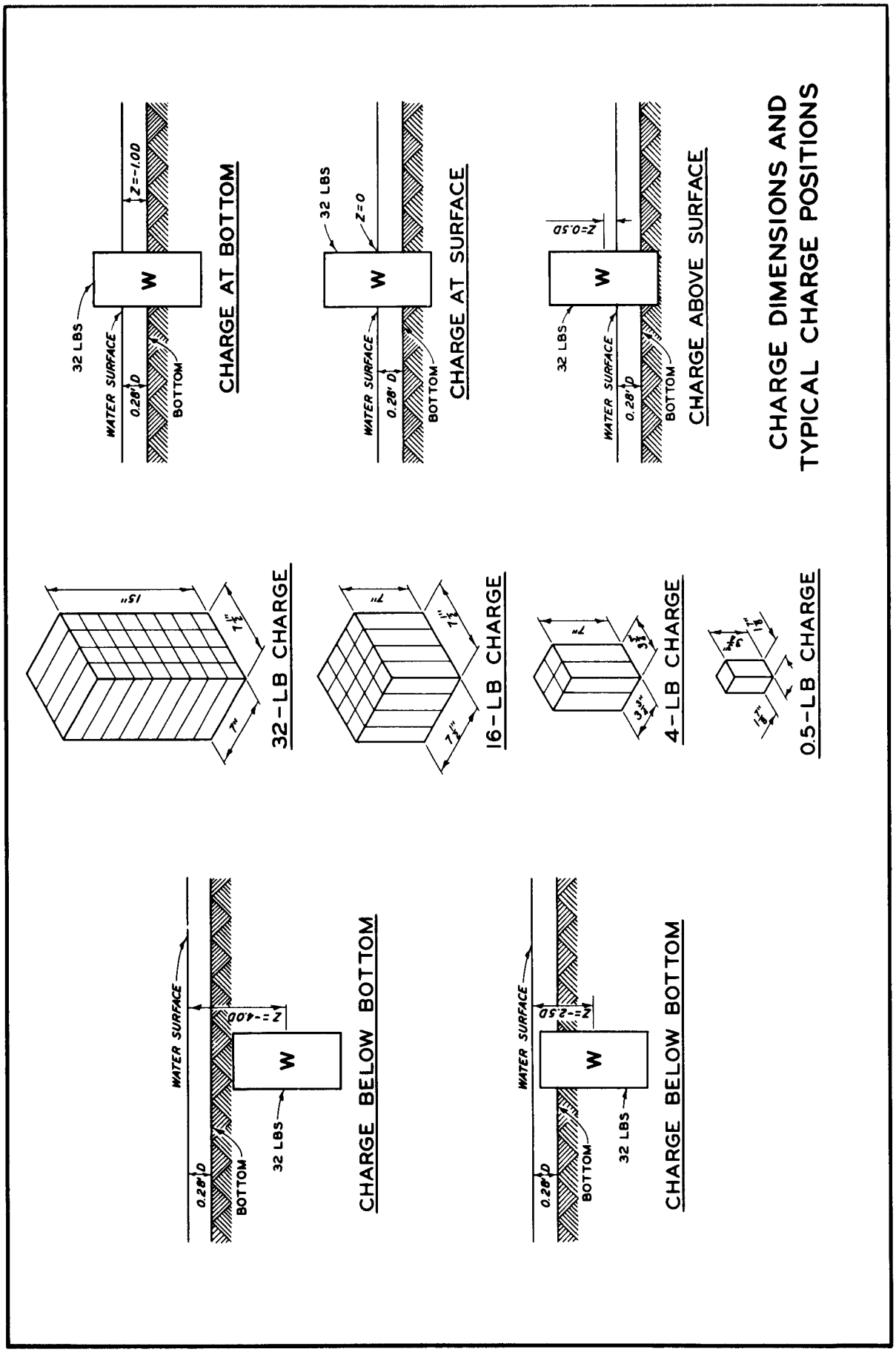
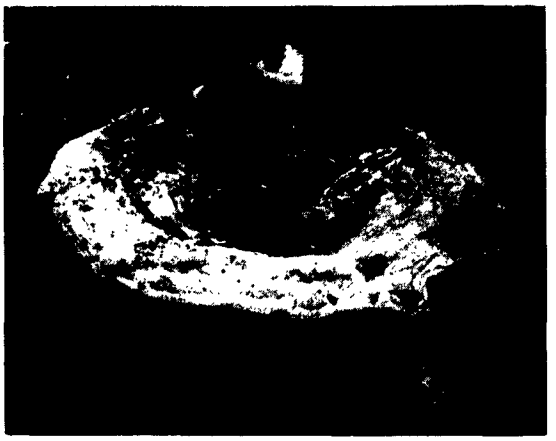

CHARGE DIMENSIONS AND TYPICAL CHARGE POSITIONS
CHARGE AT BOTTOM
32 LBS
W
Z=-1.00
WATER SURFACE
0.28' D
BOTTOM
CHARGE AT SURFACE
32 LBS
W
Z=0
WATER SURFACE
0.28' D
BOTTOM
CHARGE ABOVE SURFACE
32 LBS
W
Z=0.50
WATER SURFACE
0.28' D
BOTTOM
32-LB CHARGE
15"
7"
1 1/2"
16-LB CHARGE
7"
7 1/2"
1 1/2"
4-LB CHARGE
7"
3 1/2"
3 1/2"
0.5-LB CHARGE
1 1/2"
1"
CHARGE BELOW BOTTOM
WATER SURFACE
Z=-4.00
W
32 LBS
0.28' D
BOTTOM
CHARGE BELOW BOTTOM
WATER SURFACE
Z=-2.50
W
32 LBS
0.28' D
BOTTOM

PLATE 2

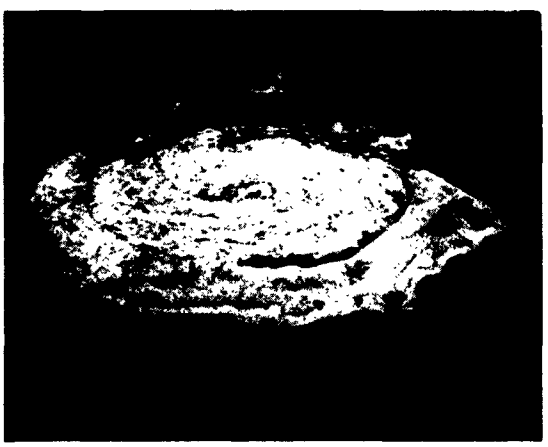
4 minutes



5.5 minutes

7.0 minutes

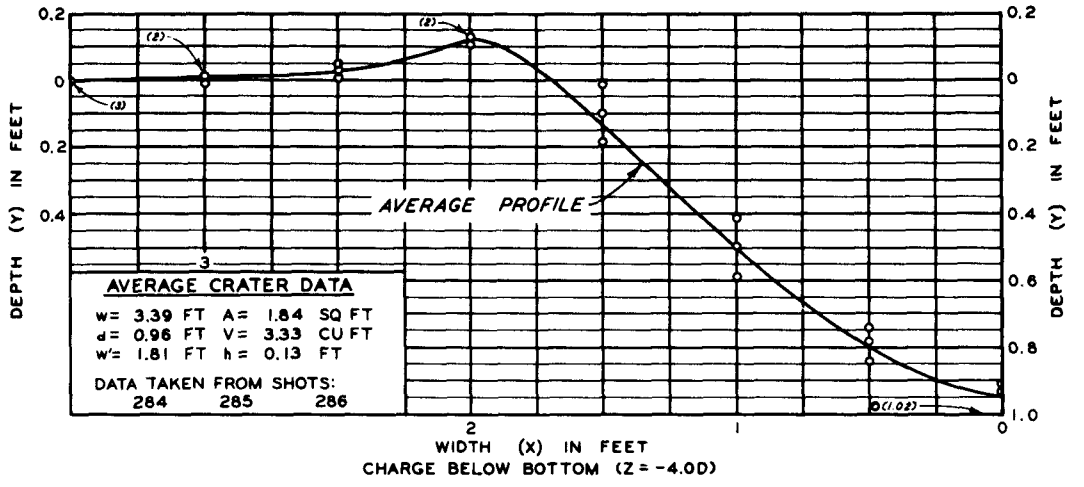
7.5 minutes

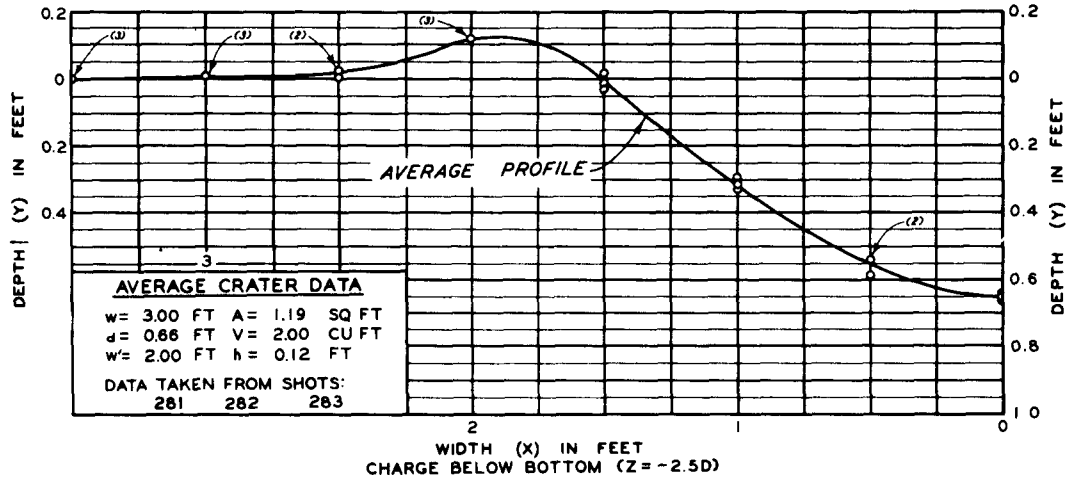


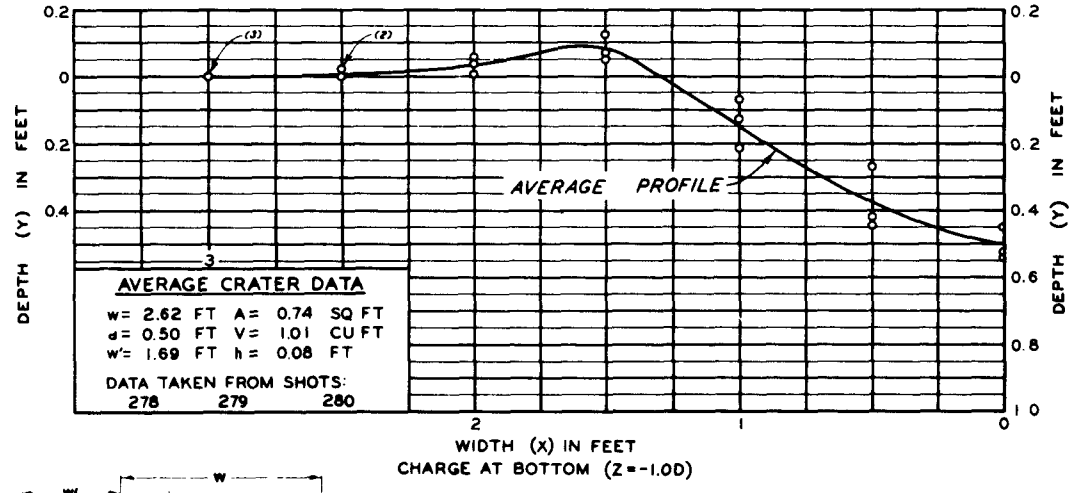
8.1 minutes

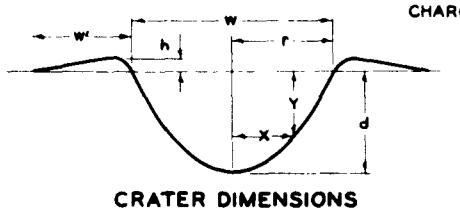
8.4 minutes

Collapse of crater lip. Crater formed by 32-lb charge detonated at a scaled depth of 90 ft below bottom
Scaled water depth, 30 ft









CRATER DIMENSIONS

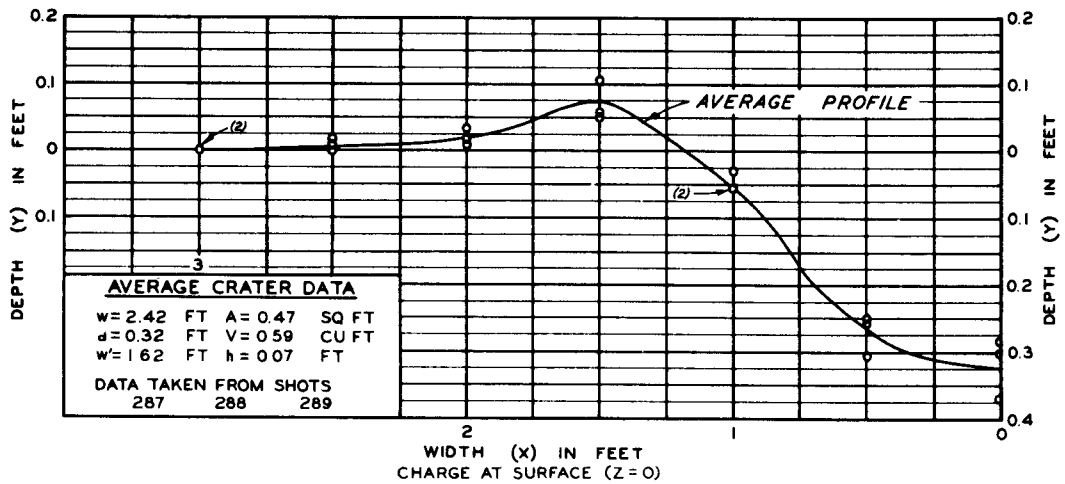
HALF-CRATER PROFILES

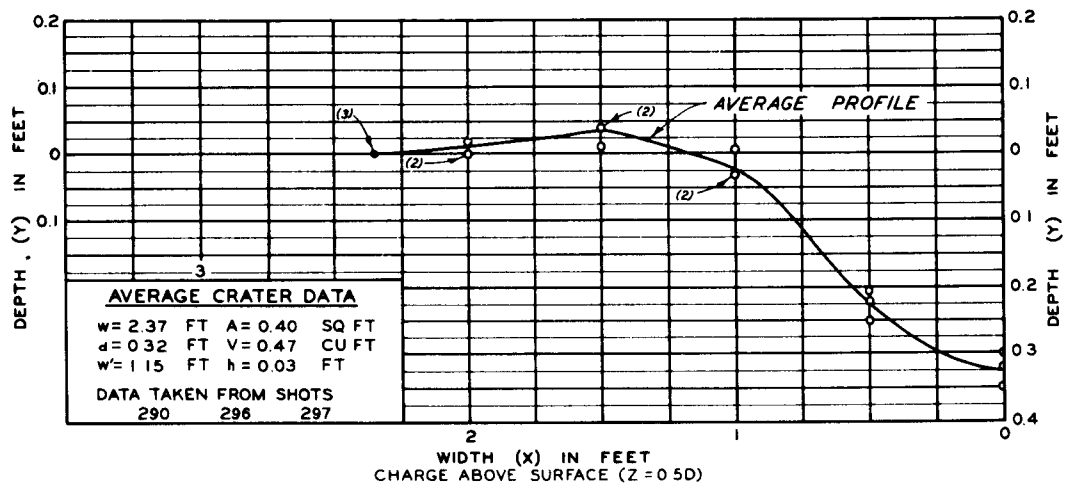
BOTTOM MATERIAL - SAND

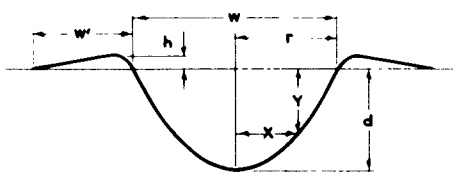
CHARGE WEIGHT - 0.5 LB

$D/W^{\frac{1}{3}} = 0.088$

PLATE 4







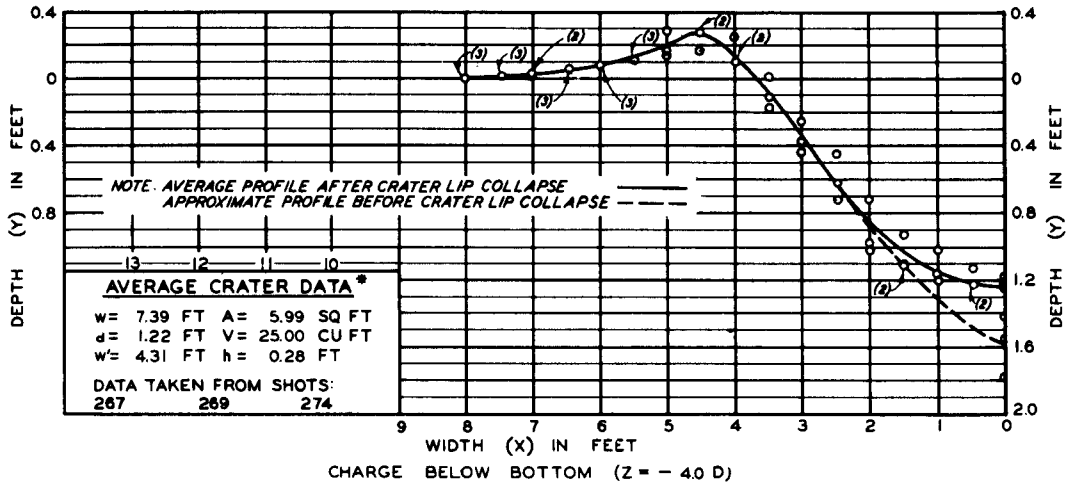
CRATER DIMENSIONS

HALF-CRATER PROFILES

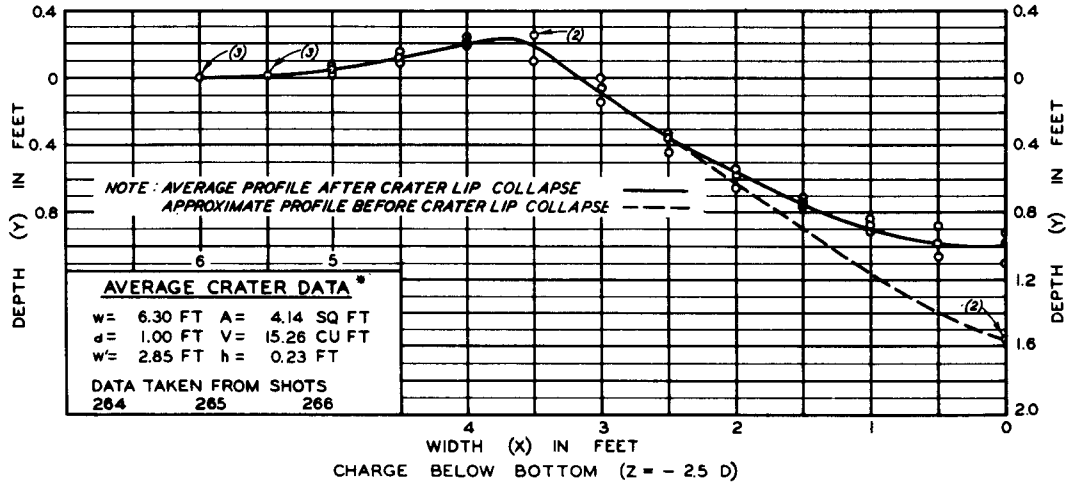
BOTTOM MATERIAL - SAND

CHARGE WEIGHT - 0.5 LB

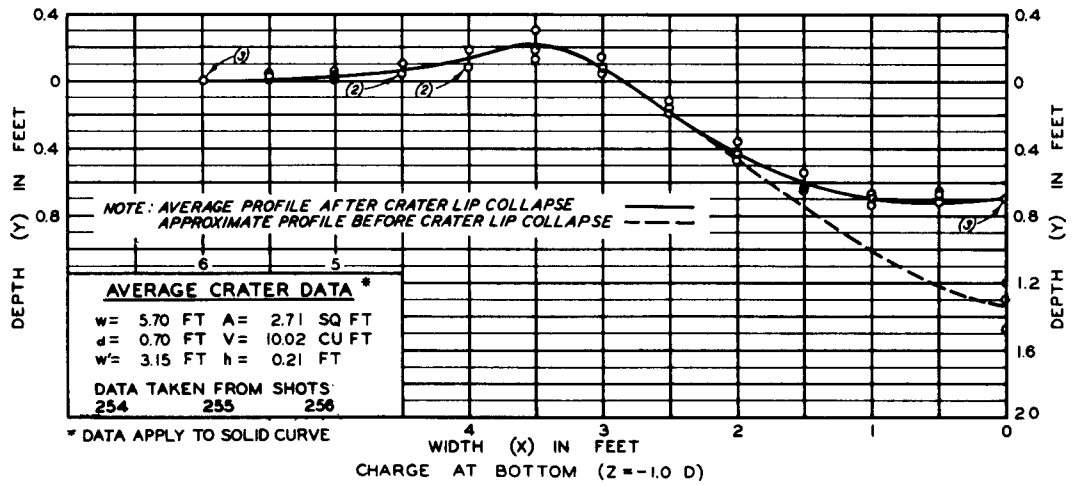
$D/W^{\frac{1}{3}} = 0.088$



CHARGE BELOW BOTTOM (Z = − 4.0 D)

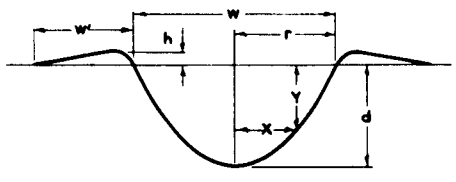


CHARGE BELOW BOTTOM (Z = − 2.5 D)



* DATA APPLY TO SOLID CURVE

CHARGE AT BOTTOM (Z = −1.0 D)



CRATER DIMENSIONS

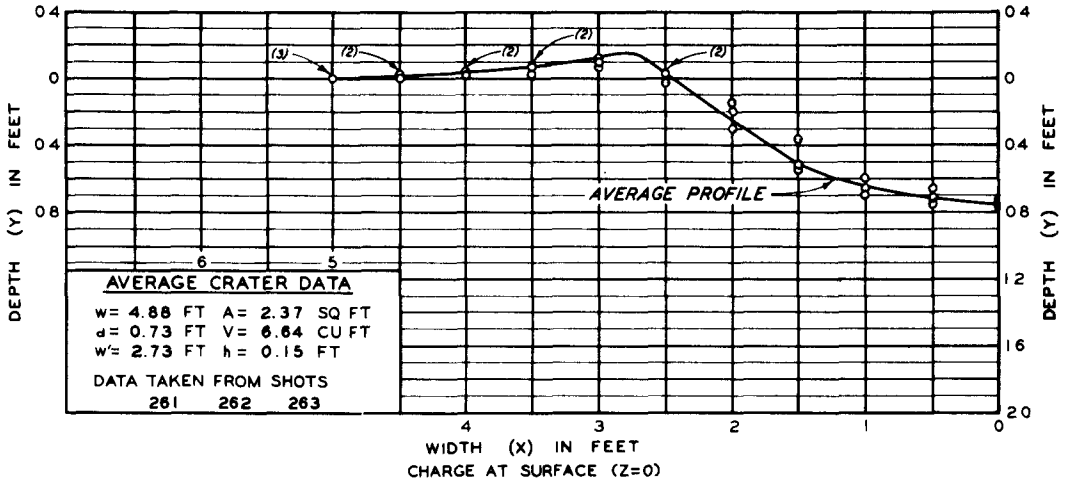
HALF-CRATER PROFILES

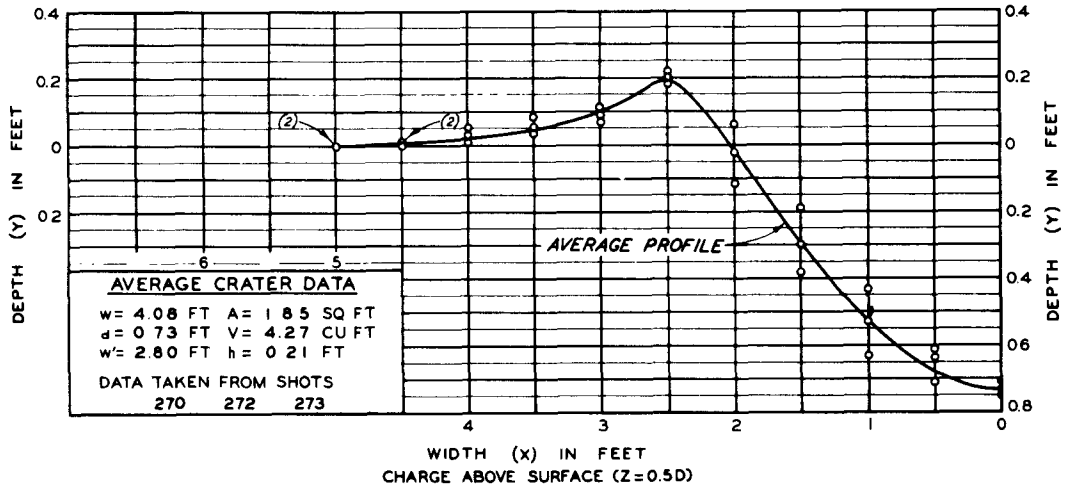
BOTTOM MATERIAL - SAND

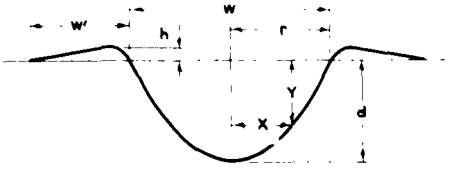
CHARGE WEIGHT - 4 LB

$D/W^{\frac{1}{3}} = 0.088$

PLATE 6



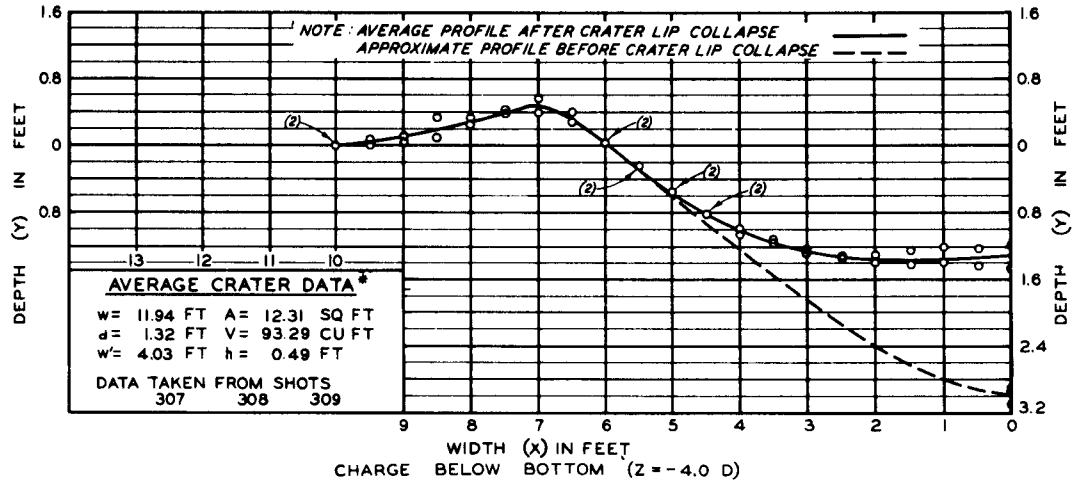


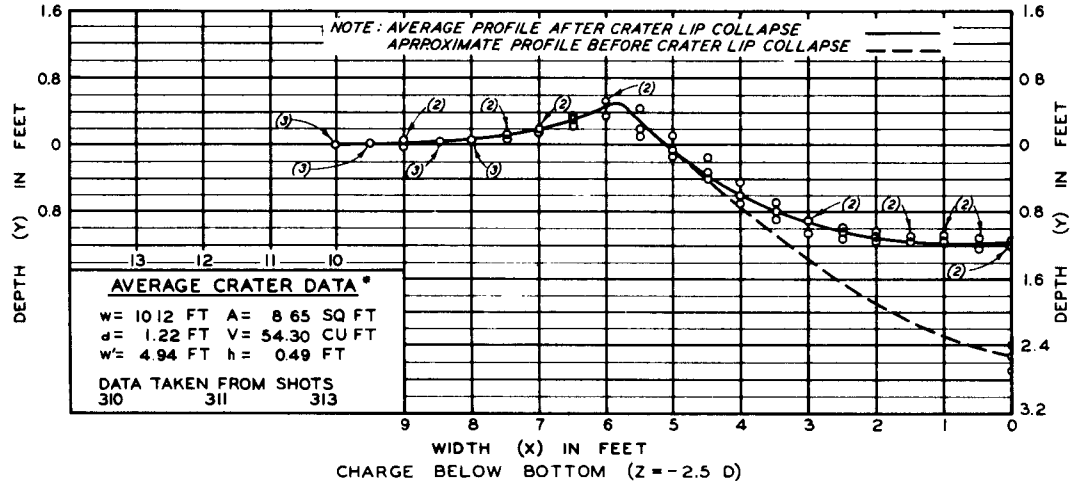


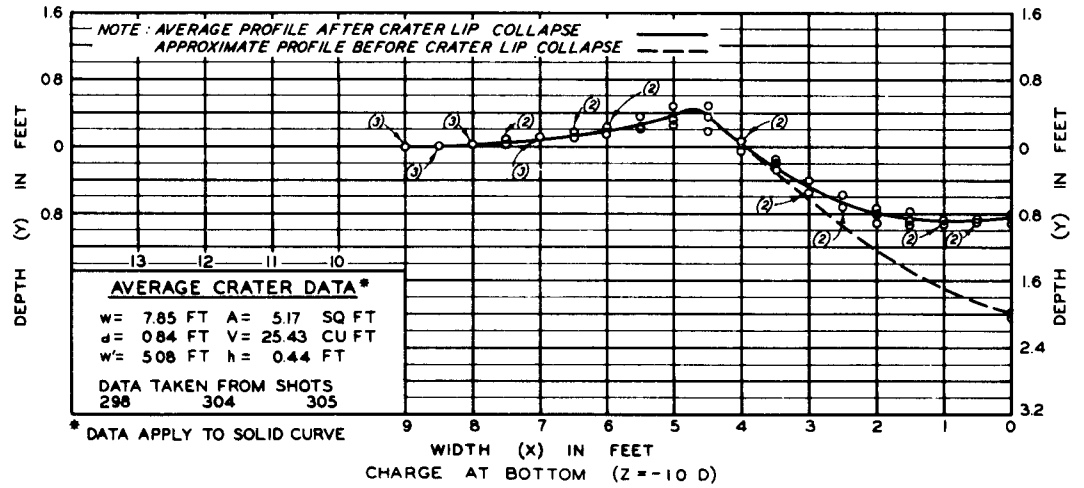
CRATER DIMENSIONS

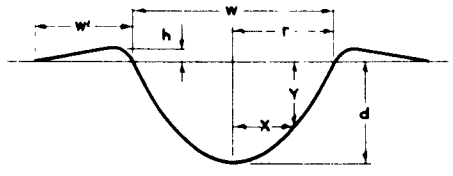
HALF-CRATER PROFILES

BOTTOM MATERIAL - SAND
CHARGE WEIGHT - 4 LB
$D/W^{\frac{1}{3}} = 0.088$









CRATER DIMENSIONS

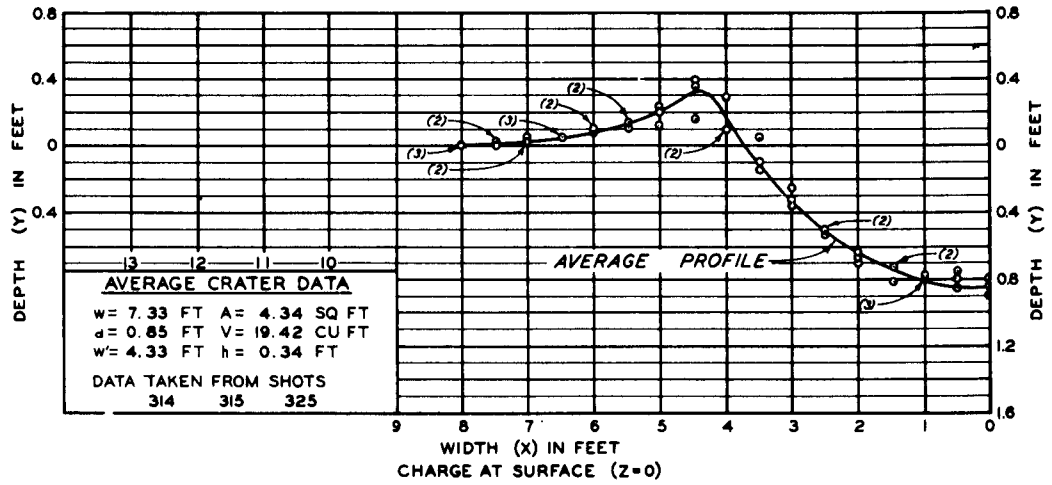
HALF-CRATER PROFILES

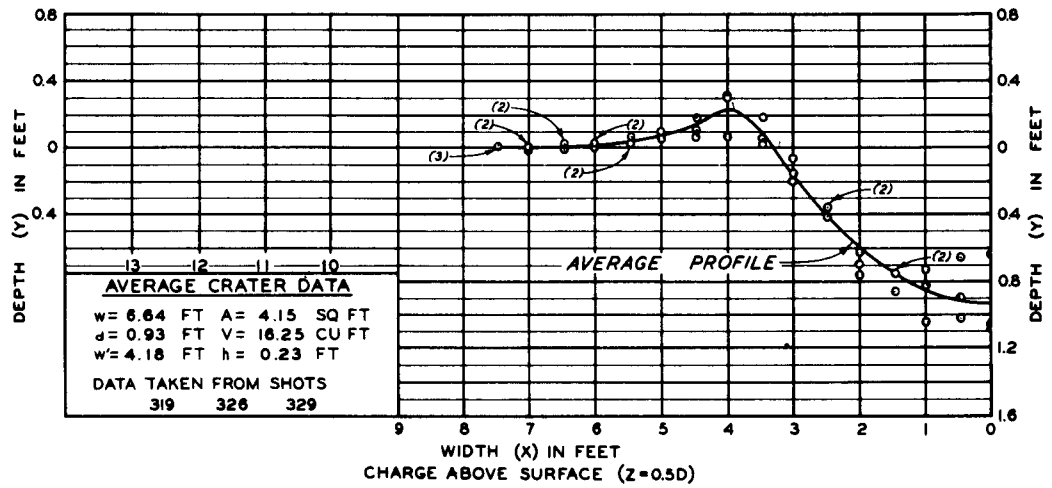
BOTTOM MATERIAL - SAND

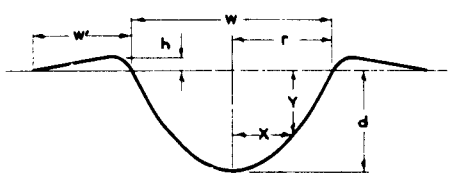
CHARGE WEIGHT --16 LB

$D/W^{\frac{1}{3}} = 0.088$

PLATE 8







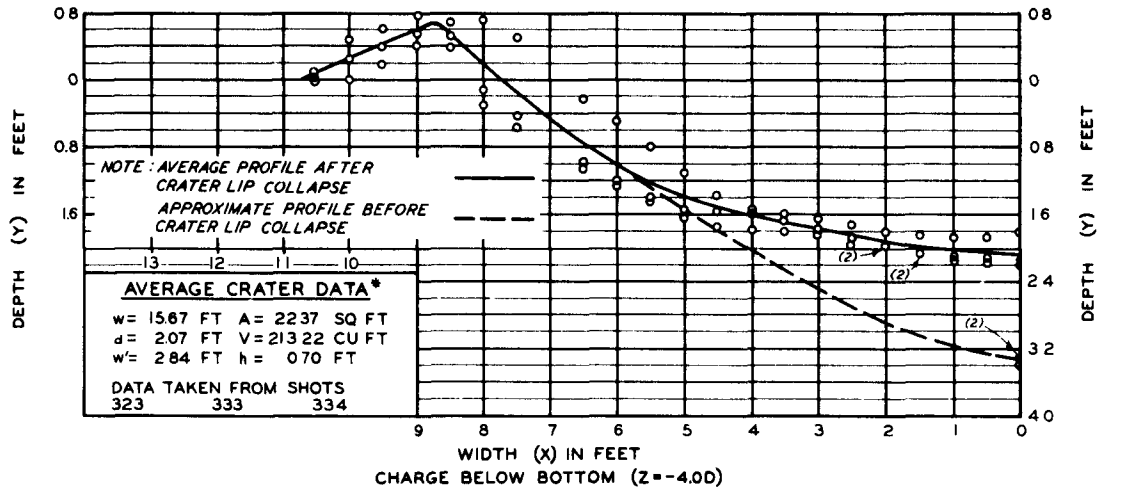
CRATER DIMENSIONS

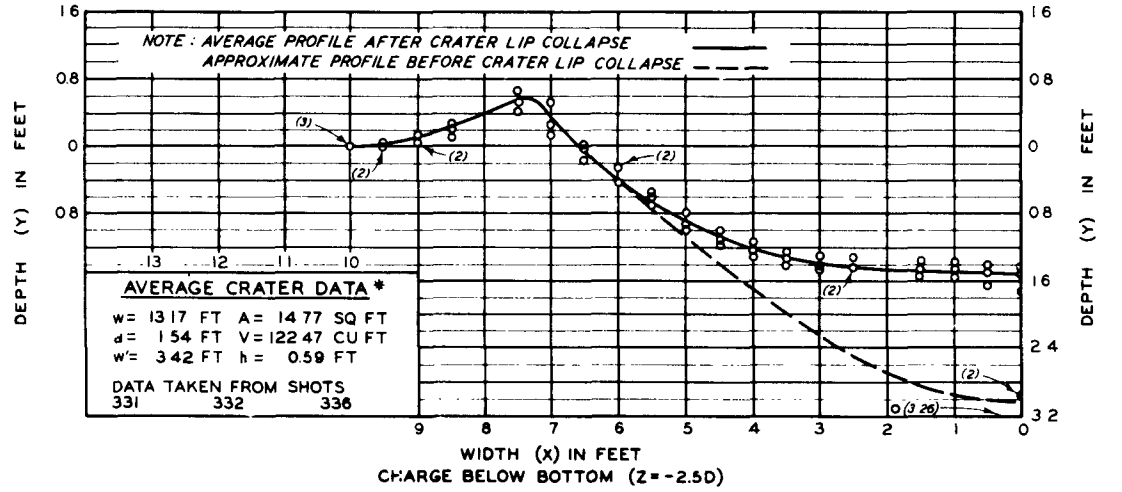
HALF-CRATER PROFILES

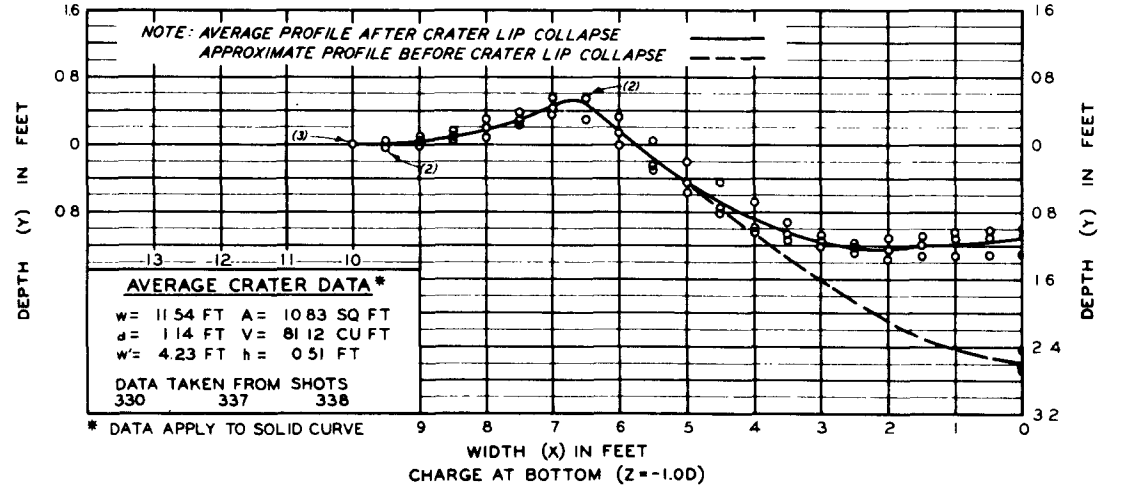
BOTTOM MATERIAL - SAND

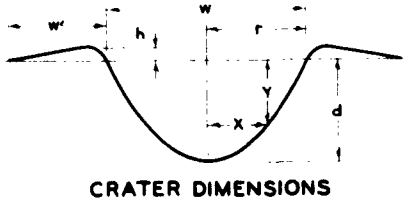
CHARGE WEIGHT - 16 LB

$D/W^{\frac{1}{3}} = 0.088$









CRATER DIMENSIONS

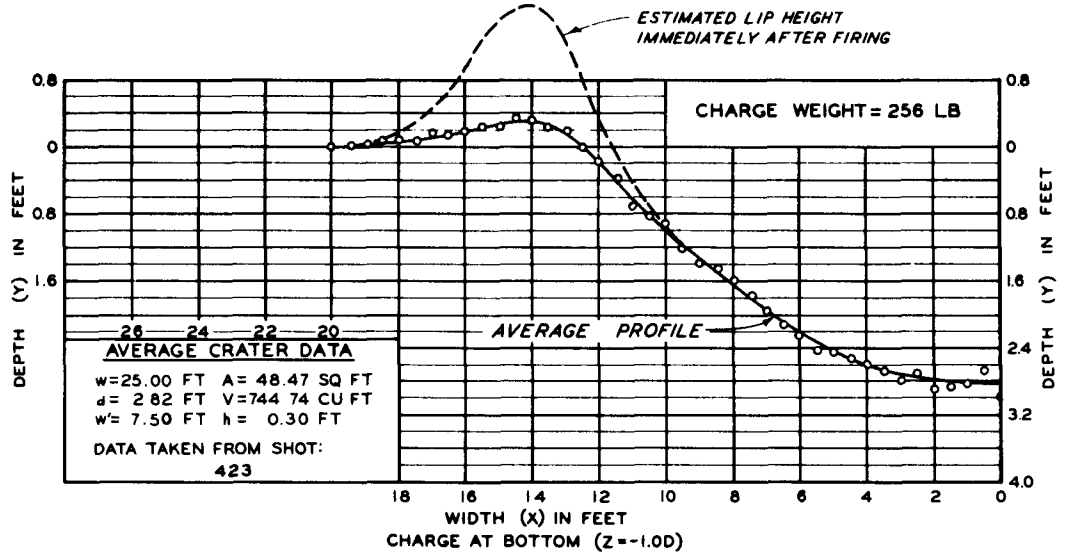
HALF-CRATER PROFILES

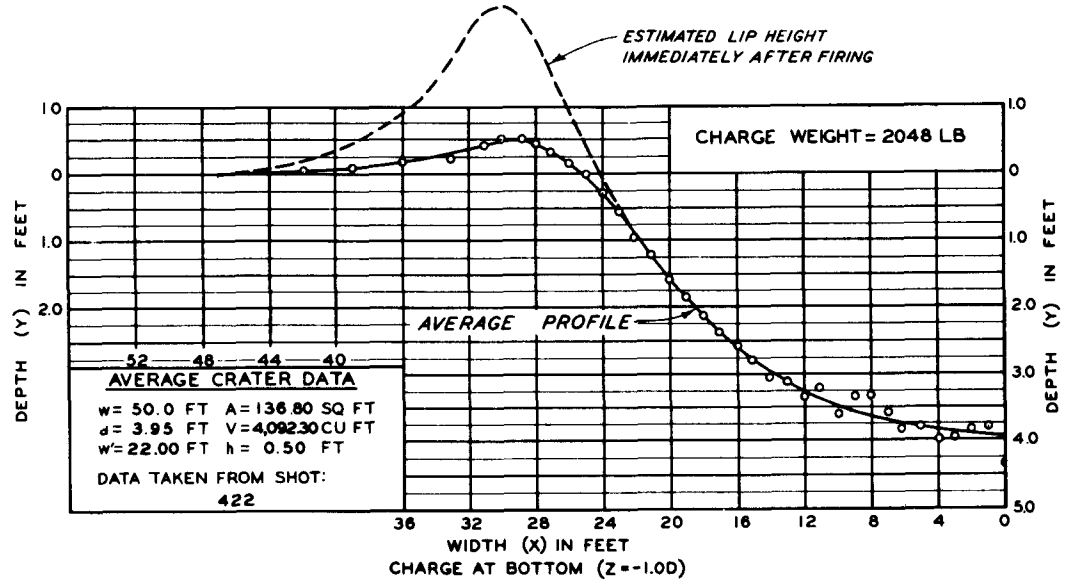
BOTTOM MATERIAL - SAND

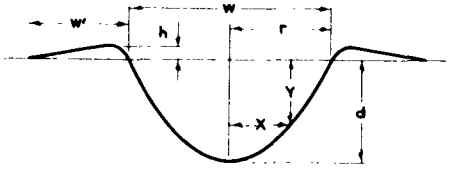
CHARGE WEIGHT — 32 LB

$D/W^{\frac{1}{3}} = 0.088$

PLATE 10







CRATER DIMENSIONS

HALF-CRATER PROFILES

BOTTOM MATERIAL - SAND

FIELD TESTS

$D/W^{\frac{1}{3}} = 0.088$

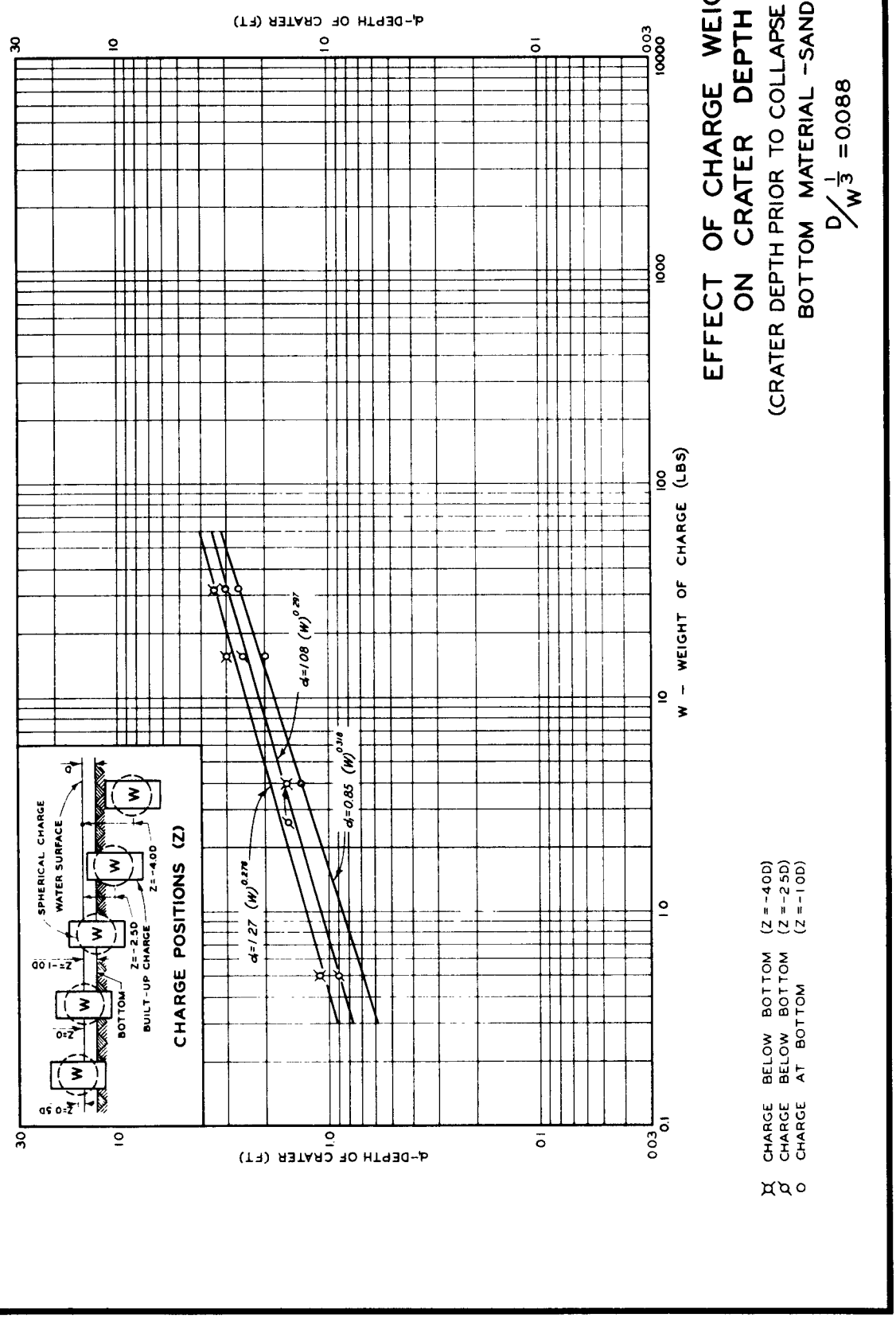

EFFECT OF CHARGE WEIGHT
ON CRATER DEPTH
(CRATER DEPTH PRIOR TO COLLAPSE OF LIP)
BOTTOM MATERIAL -SAND
$D/W^{\frac{1}{3}} = 0.088$
d-DEPTH OF CRATER (FT)
W - WEIGHT OF CHARGE (LBS)
$d=1.27\ (W)^{0.278}$
$d=1.08\ (W)^{0.287}$
$d=0.85\ (W)^{0.318}$
CHARGE POSITIONS (Z)
SPHERICAL CHARGE
WATER SURFACE
BOTTOM
BUILT-UP CHARGE
Z=-4.00
Z=-2.50
Z=-1.00
Z=0
Z=0.50
CHARGE BELOW BOTTOM (Z=-4.0D)
CHARGE BELOW BOTTOM (Z=-2.5D)
CHARGE AT BOTTOM (Z=-1.0D)

PLATE 12

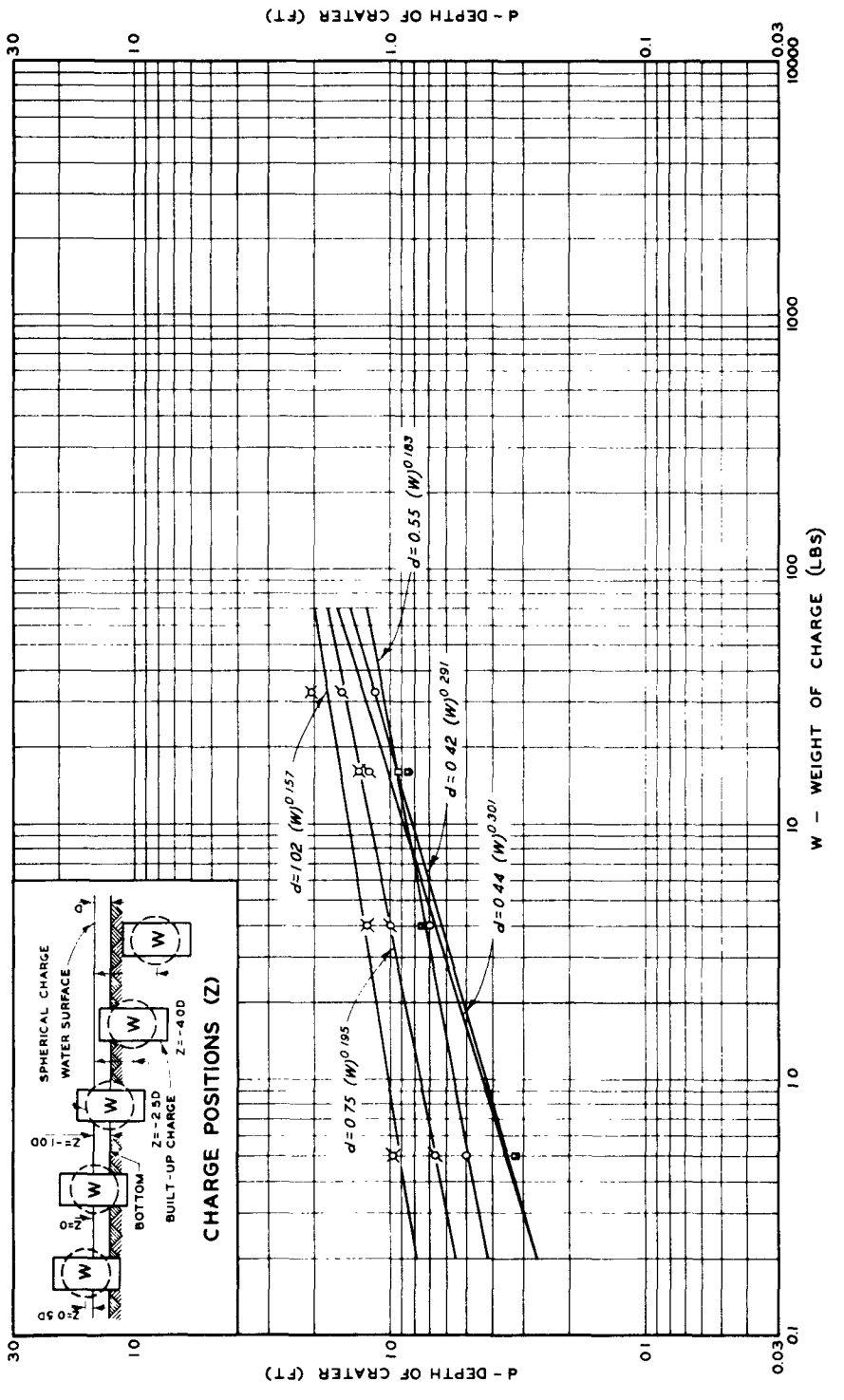

EFFECT OF CHARGE WEIGHT
ON CRATER DEPTH
BOTTOM MATERIAL - SAND
$D/W^{\frac{1}{3}} = 0.088$
d - DEPTH OF CRATER (FT)
W - WEIGHT OF CHARGE (LBS)
$d = 1.02\ (W)^{0.157}$
$d = 0.55\ (W)^{0.183}$
$d = 0.42\ (W)^{0.291}$
$d = 0.44\ (W)^{0.301}$
$d = 0.75\ (W)^{0.195}$
CHARGE POSITIONS (Z)
SPHERICAL CHARGE
WATER SURFACE
BOTTOM
BUILT-UP CHARGE
Z = 2.5D
Z = 4.0D
Z = 1.0D
Z = 0
Z = 0.5D
CHARGE BELOW BOTTOM (Z = -4.0 D)
CHARGE BELOW BOTTOM (Z = -2.5 D)
CHARGE AT BOTTOM (Z = -1.0 D)
CHARGE AT SURFACE (Z = 0)
CHARGE ABOVE SURFACE (Z = 0.5 D)

PLATE 13

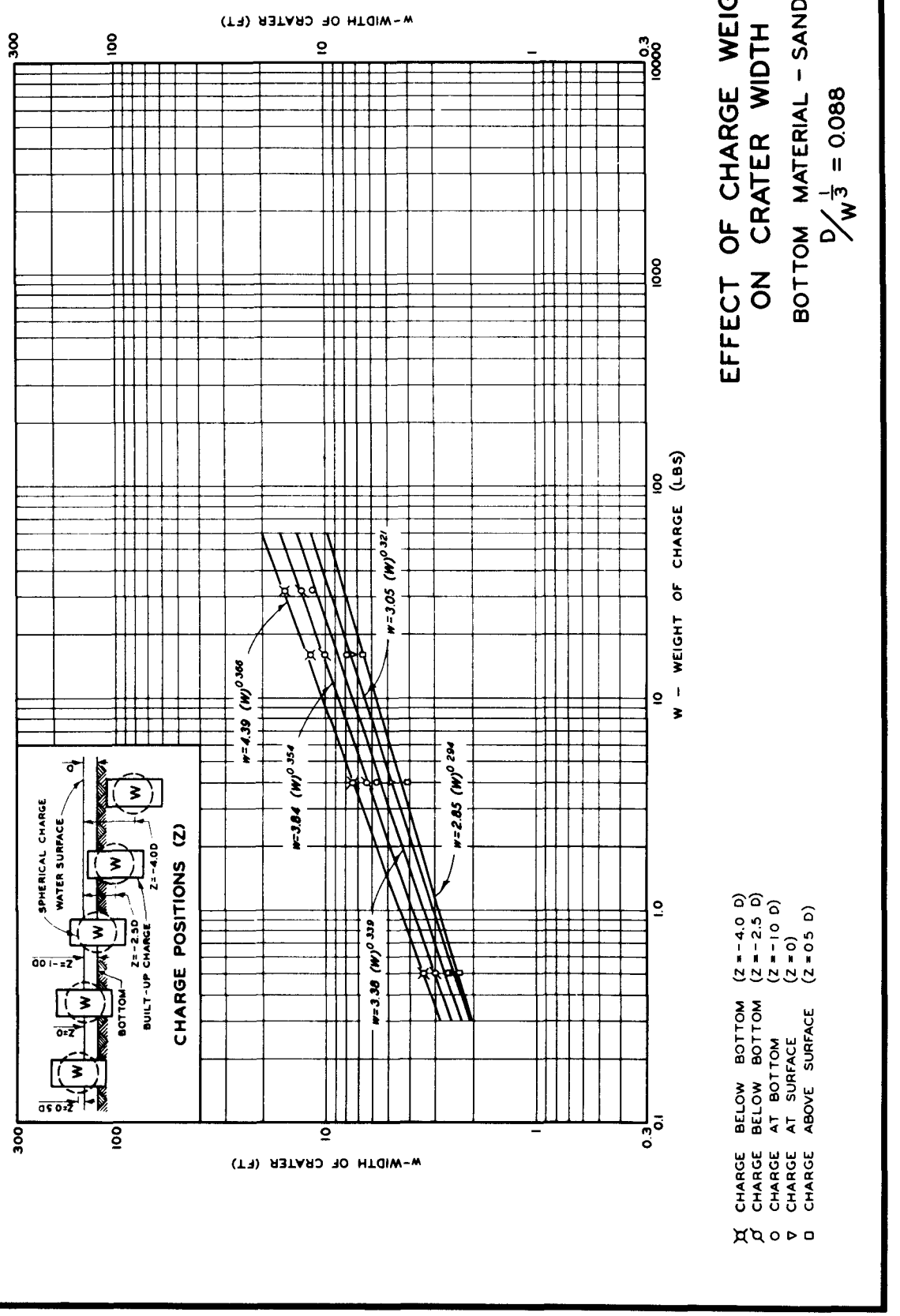

EFFECT OF CHARGE WEIGHT
ON CRATER WIDTH
BOTTOM MATERIAL - SAND
$D/W^{\frac{1}{3}} = 0.088$
W-WIDTH OF CRATER (FT)
W - WEIGHT OF CHARGE (LBS)
W=4.39 (W)^0.366
W=3.84 (W)^0.354
W=3.38 (W)^0.339
W=3.05 (W)^0.321
W=2.85 (W)^0.294
CHARGE POSITIONS (Z)
SPHERICAL CHARGE
WATER SURFACE
BOTTOM
BUILT-UP CHARGE
Z=-4.0D
Z=-2.5D
Z=-1.0D
Z=0
Z=0.5D
CHARGE BELOW BOTTOM (Z=-4.0 D)
CHARGE BELOW BOTTOM (Z=-2.5 D)
CHARGE AT BOTTOM (Z=-1.0 D)
CHARGE AT SURFACE (Z=0)
CHARGE ABOVE SURFACE (Z=0.5 D)

PLATE 14

EFFECT OF CHARGE WEIGHT ON CRATER LIP HEIGHT

BOTTOM MATERIAL - SAND

$D/W^{\frac{1}{3}} = 0.088$

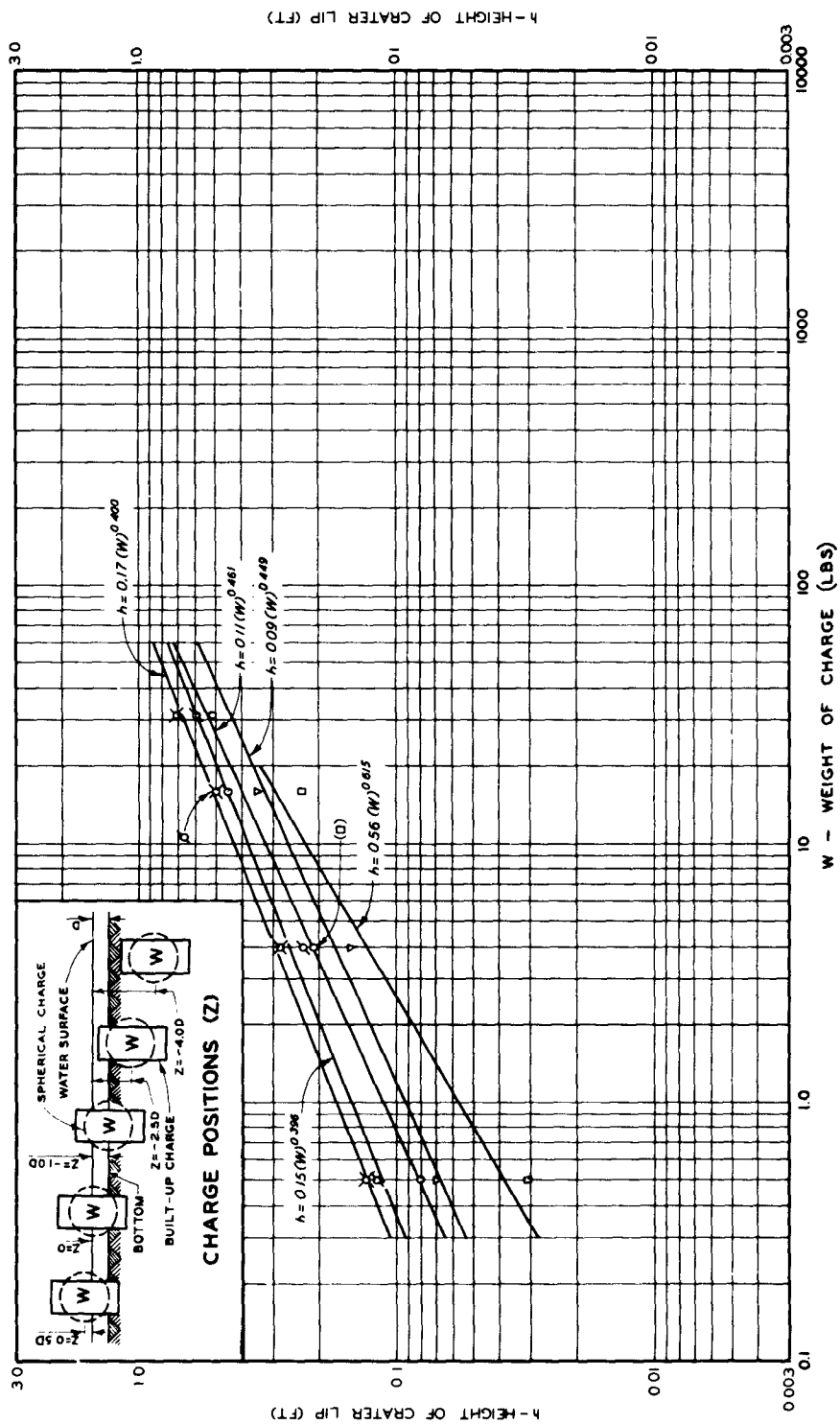
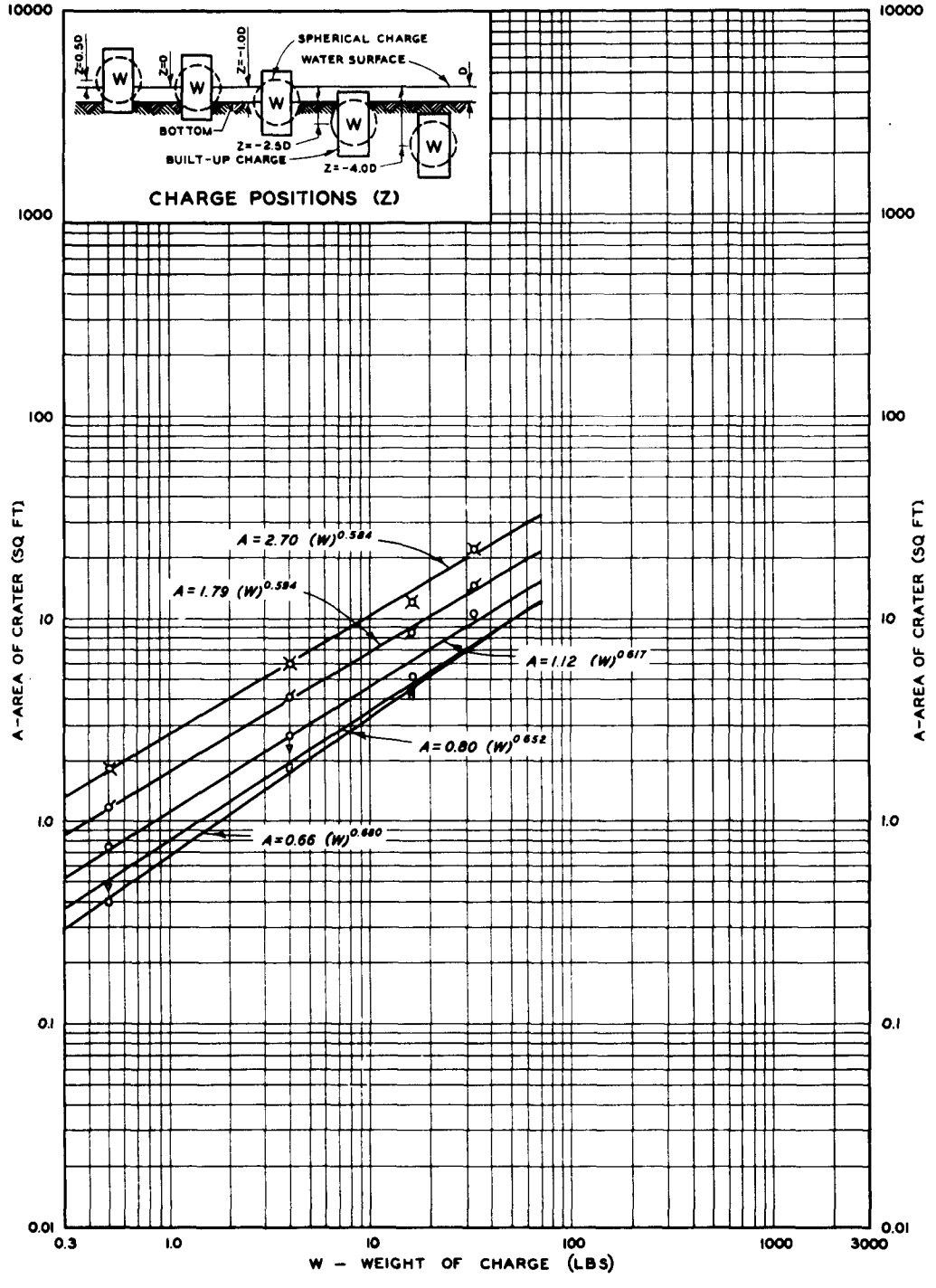


PLATE 15



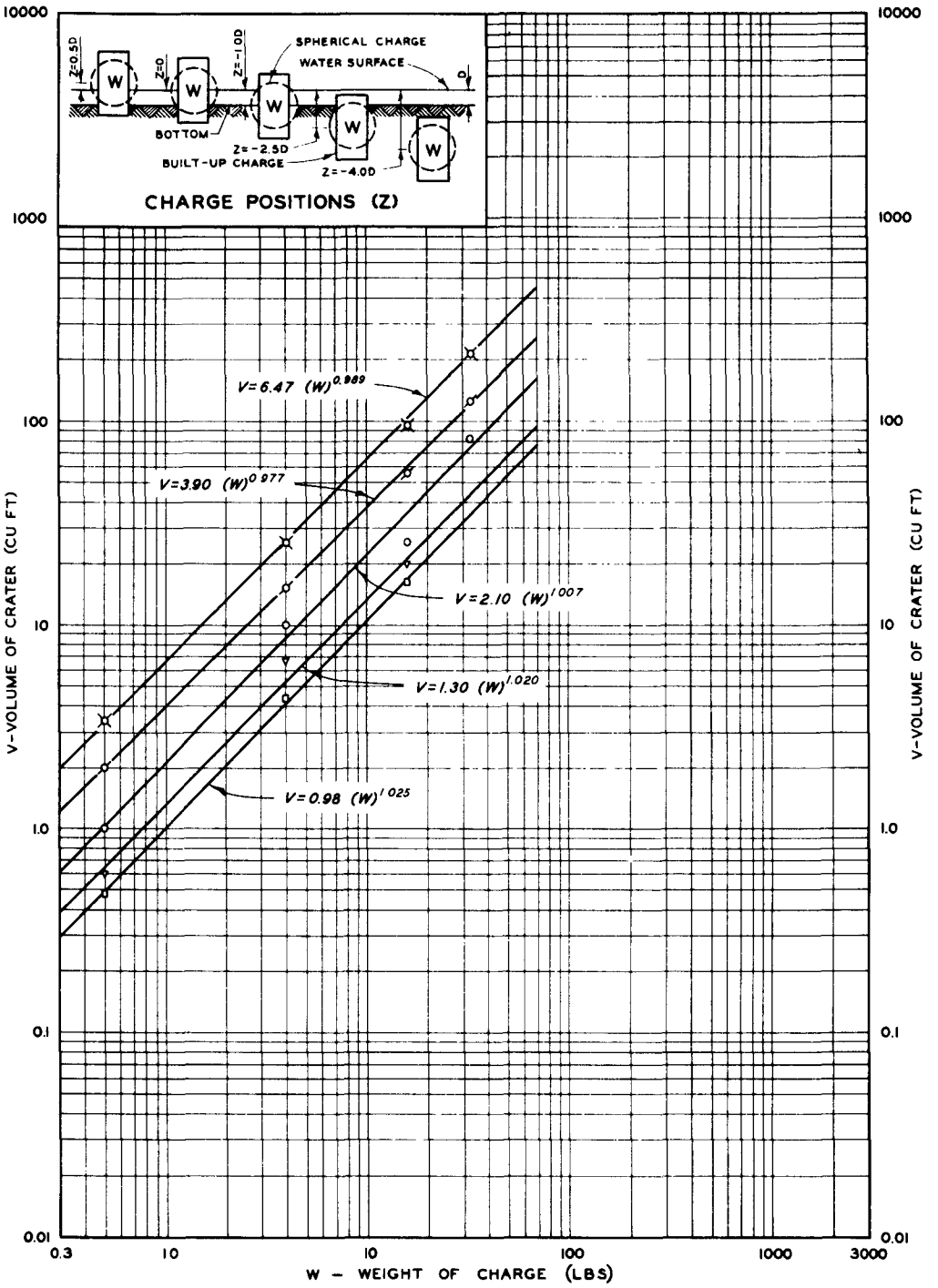
⌘ CHARGE BELOW BOTTOM (Z = -4.0 D)
⌘ CHARGE BELOW BOTTOM (Z = -2.5 D)
○ CHARGE AT BOTTOM (Z = -1.0 D)
▽ CHARGE AT SURFACE (Z = 0)
□ CHARGE ABOVE SURFACE (Z = 0.5 D)

EFFECT OF CHARGE WEIGHT ON CRATER AREA

BOTTOM MATERIAL - SAND

$D/W^{\frac{1}{3}} = 0.088$

PLATE 16



⧖ CHARGE BELOW BOTTOM (Z = -4.0 D)
⧖ CHARGE BELOW BOTTOM (Z = -2.5 D)
○ CHARGE AT BOTTOM (Z = -1.0 D)
▽ CHARGE AT SURFACE (Z = 0)
□ CHARGE ABOVE SURFACE (Z = 0.5 D)

EFFECT OF CHARGE WEIGHT ON CRATER VOLUME

BOTTOM MATERIAL - SAND

$D/W^{\frac{1}{3}} = 0.088$

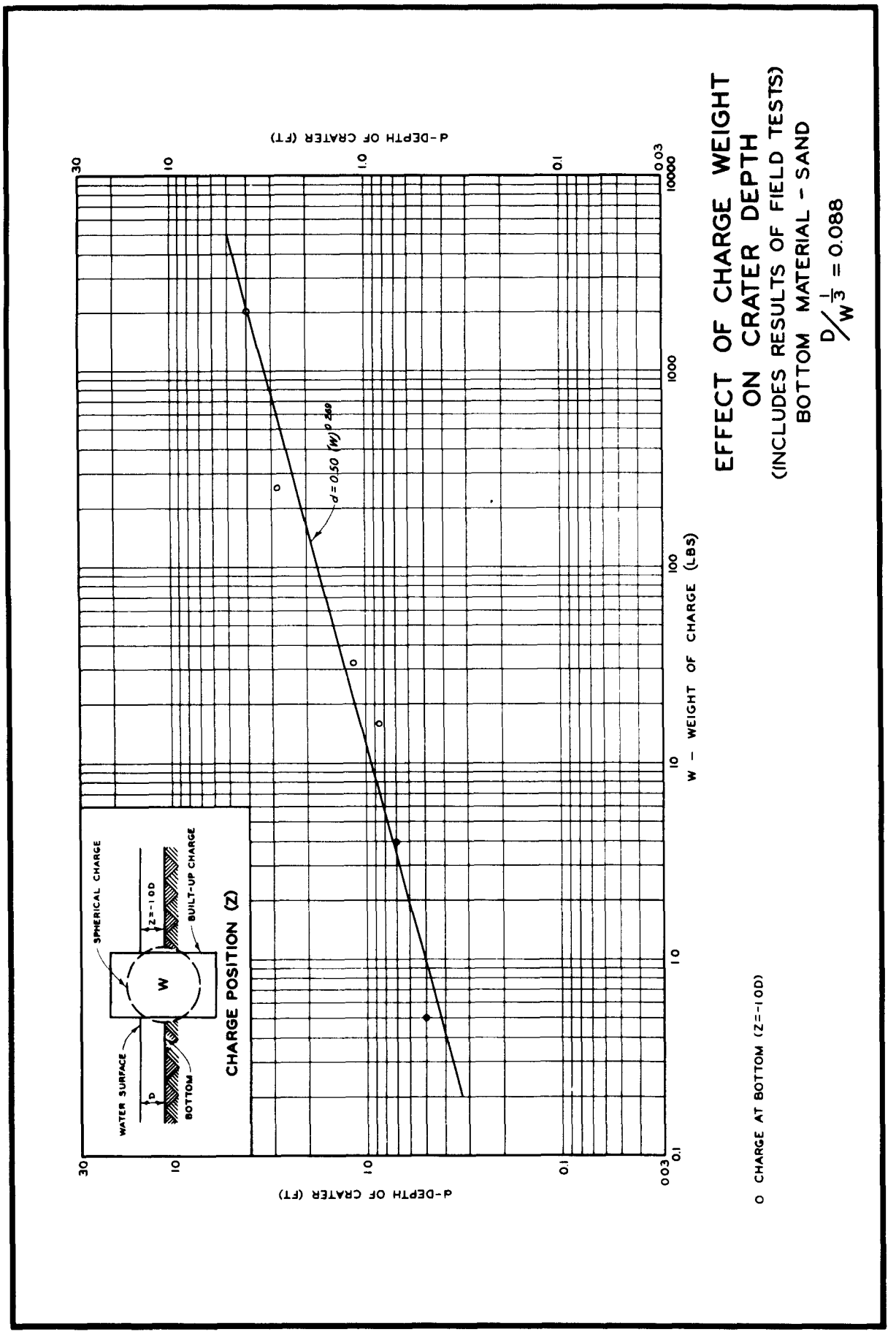
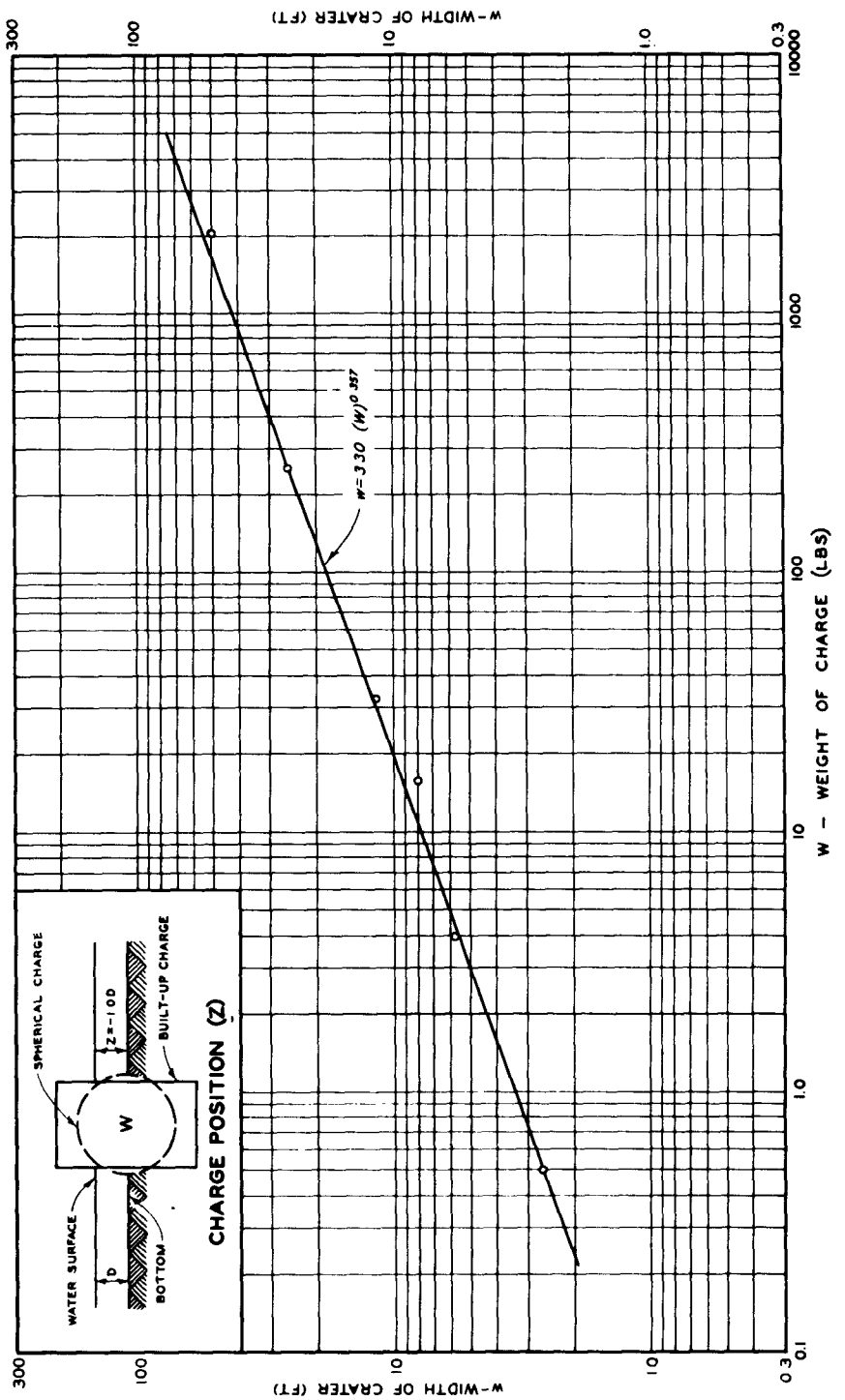

EFFECT OF CHARGE WEIGHT
ON CRATER DEPTH
(INCLUDES RESULTS OF FIELD TESTS)
BOTTOM MATERIAL - SAND
$D/W^{\frac{1}{3}} = 0.088$
d = 0.50 (W)^0.360
W - WEIGHT OF CHARGE (LBS)
d-DEPTH OF CRATER (FT)
O CHARGE AT BOTTOM (Z=1.0D)
CHARGE POSITION (Z)
SPHERICAL CHARGE
BUILT-UP CHARGE
Z=1.0D
W
WATER SURFACE
D
BOTTOM

PLATE 18


EFFECT OF CHARGE WEIGHT
ON CRATER WIDTH
(INCLUDES RESULTS OF FIELD TESTS)
BOTTOM MATERIAL - SAND
$D/W^{\frac{1}{3}} = 0.088$
W - WEIGHT OF CHARGE (LBS)
W-WIDTH OF CRATER (FT)
W=330 (W)^0.857
CHARGE POSITION (Z)
SPHERICAL CHARGE
BUILT-UP CHARGE
Z=-1.0D
WATER SURFACE
BOTTOM
D
W
O CHARGE AT BOTTOM (Z=-1.0D)

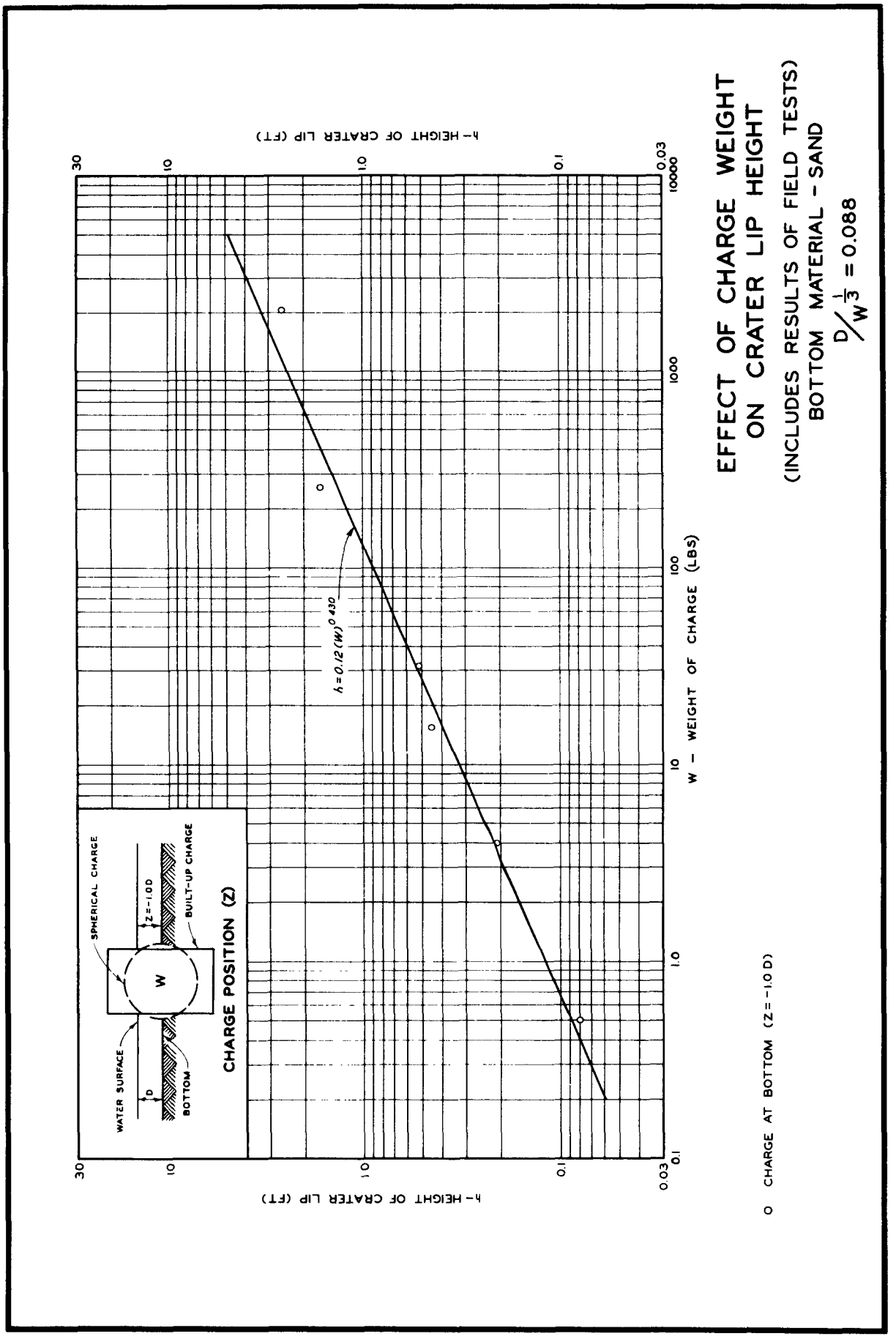
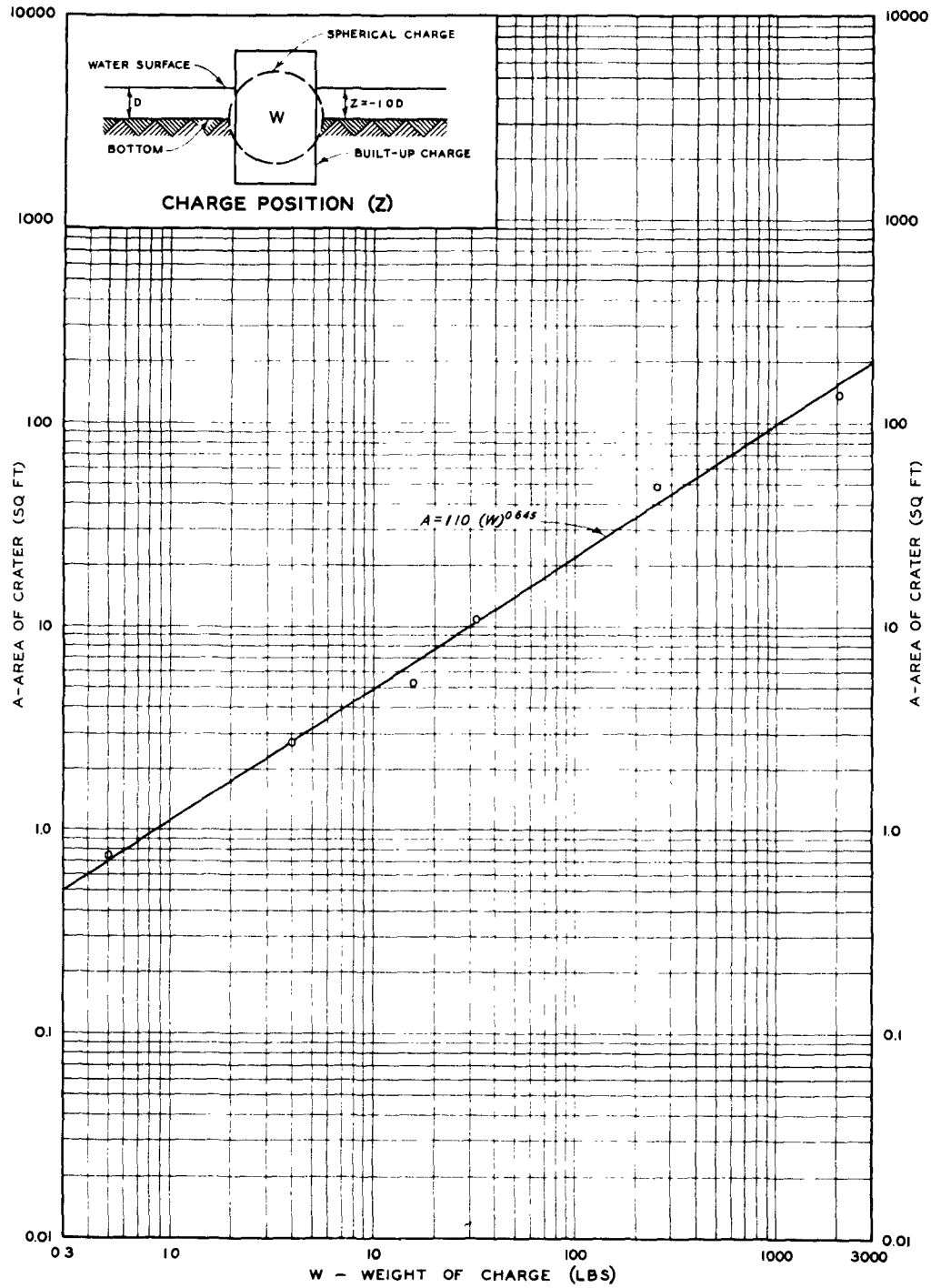

EFFECT OF CHARGE WEIGHT
ON CRATER LIP HEIGHT
(INCLUDES RESULTS OF FIELD TESTS)
BOTTOM MATERIAL - SAND
$D/W^{\frac{1}{3}} = 0.088$
h - HEIGHT OF CRATER LIP (FT)
W - WEIGHT OF CHARGE (LBS)
$h = 0.12\,(W)^{0.430}$
O CHARGE AT BOTTOM (Z=-1.0 D)
CHARGE POSITION (Z)
SPHERICAL CHARGE
BUILT-UP CHARGE
WATER SURFACE
BOTTOM
Z=-1.0D
D
W

PLATE 20



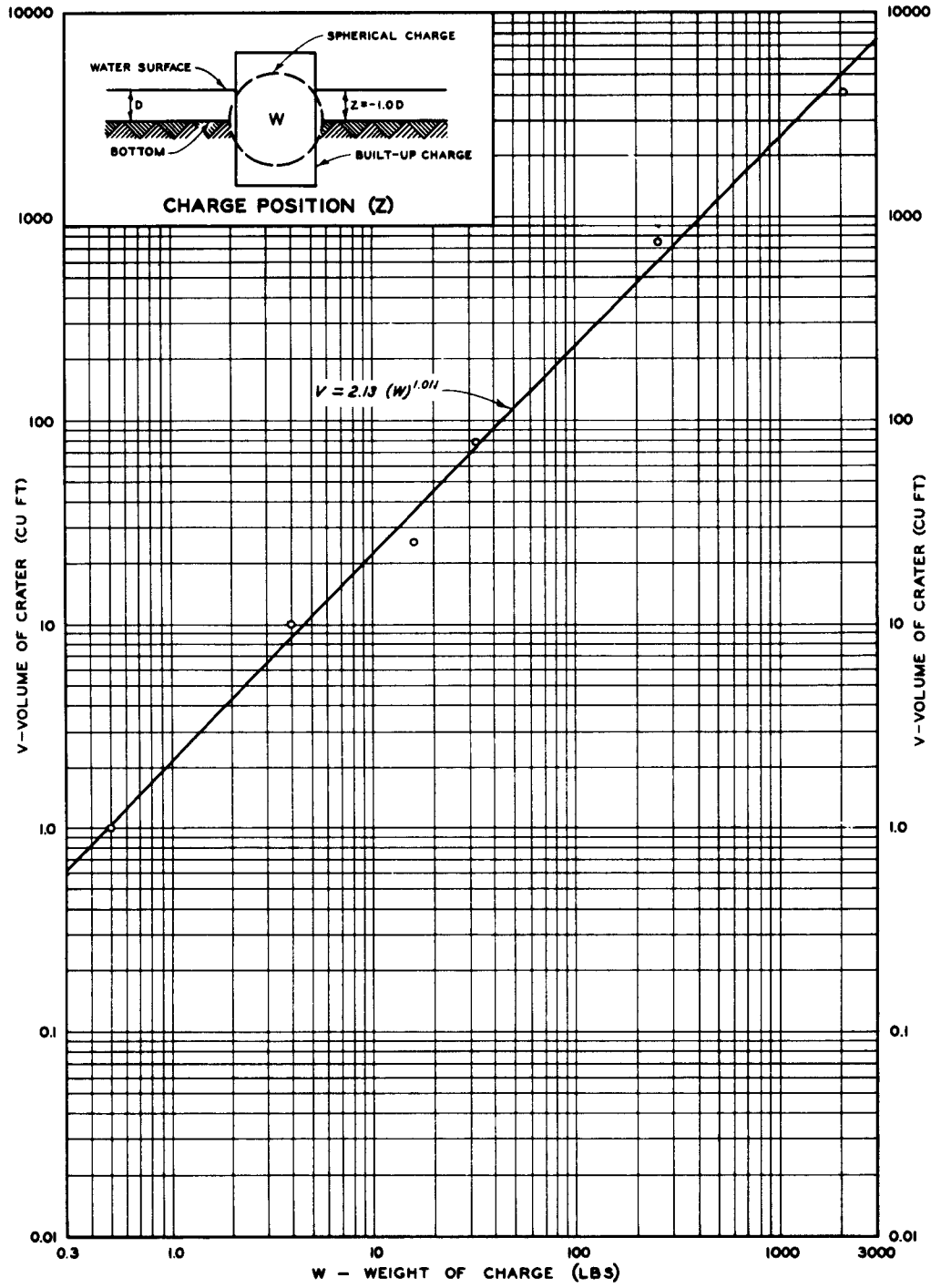
O CHARGE AT BOTTOM (Z=-1.0D)

EFFECT OF CHARGE WEIGHT ON CRATER AREA

(INCLUDES RESULTS OF FIELD TESTS)

BOTTOM MATERIAL – SAND

$D/W^{\frac{1}{3}} = 0.088$



O CHARGE AT BOTTOM (Z=-1.0D)

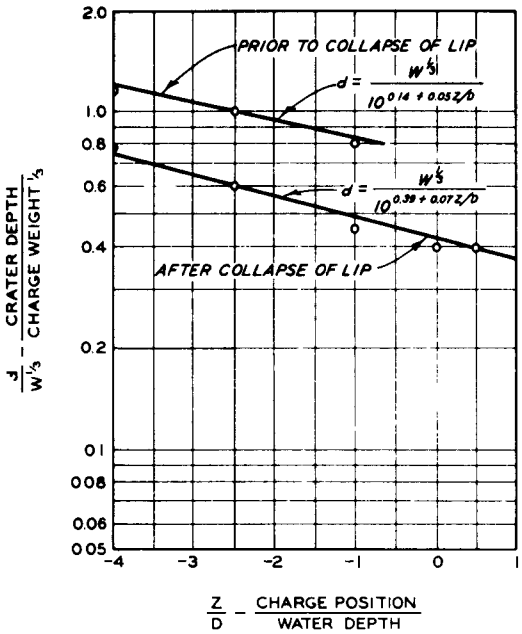
EFFECT OF CHARGE WEIGHT ON CRATER VOLUME

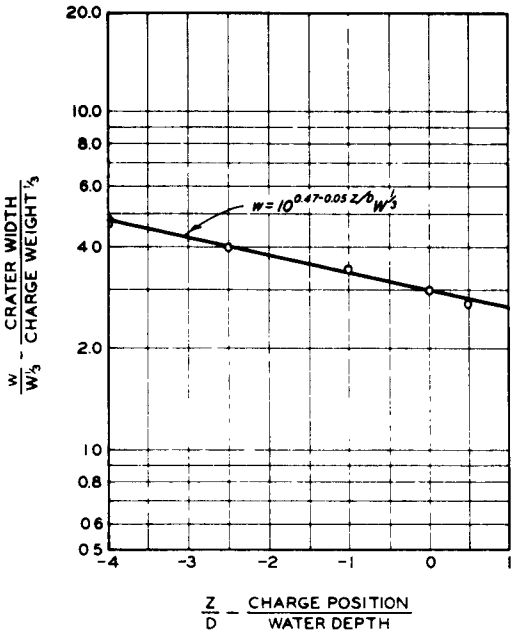
(INCLUDES RESULTS OF FIELD TESTS)

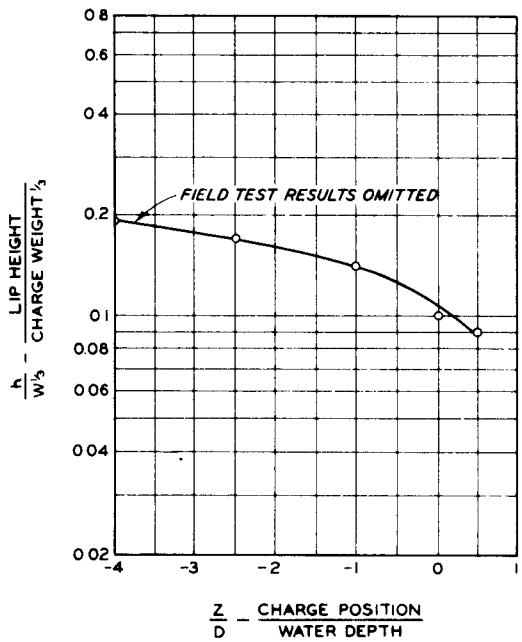
BOTTOM MATERIAL — SAND

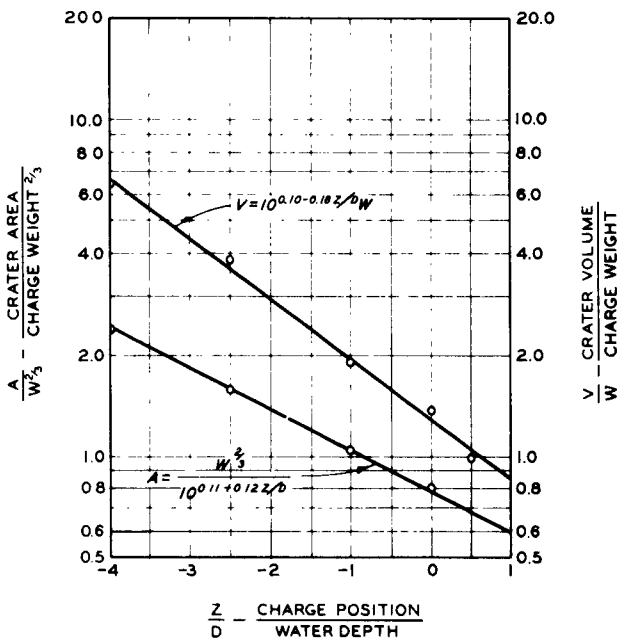
$D/W^{\frac{1}{3}} = 0.088$

PLATE 22







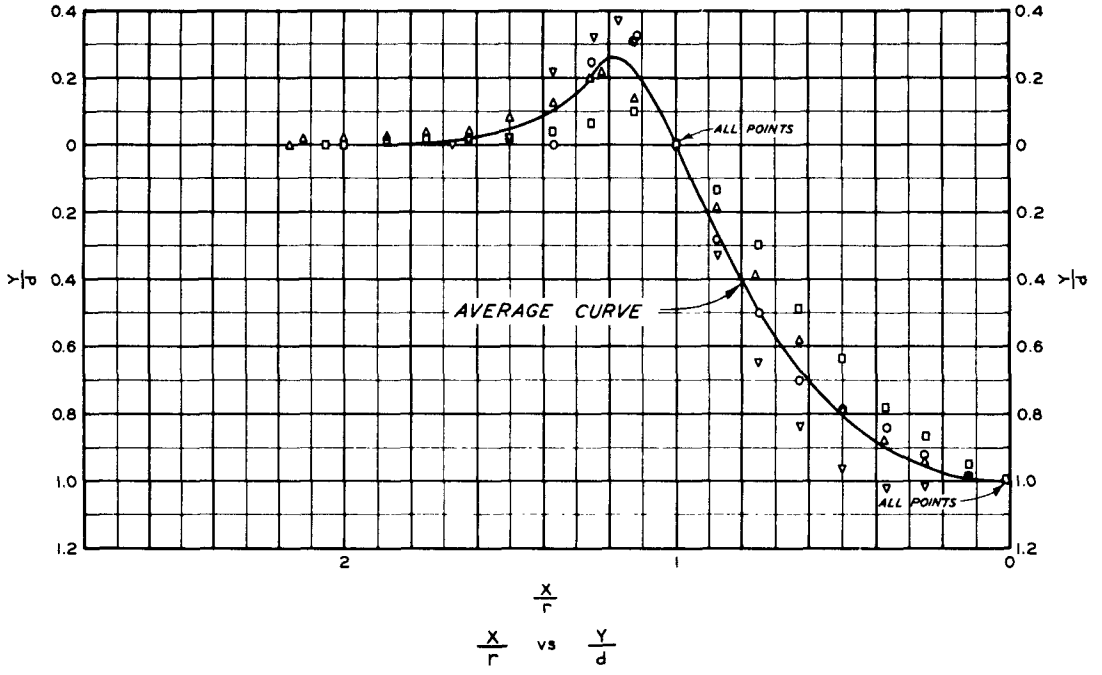


EFFECT OF CHARGE POSITION ON REDUCED CRATER DIMENSIONS

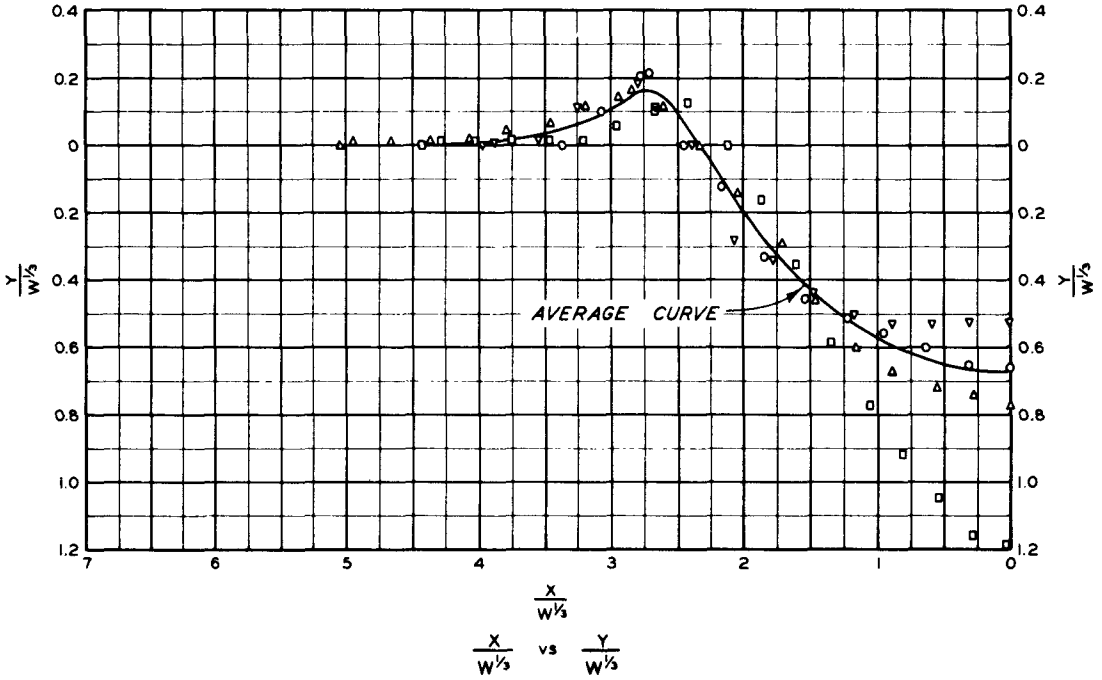
(INCLUDES RESULTS OF FIELD TESTS)

BOTTOM MATERIAL – SAND

$D / W^{\frac{1}{3}} = 0.088$



$\frac{X}{r}$ vs $\frac{Y}{d}$



$\frac{X}{W^{1/3}}$ vs $\frac{Y}{W^{1/3}}$

○ 32-LB CHARGE
▽ 16-LB CHARGE
△ 4-LB CHARGE
□ 05-LB CHARGE

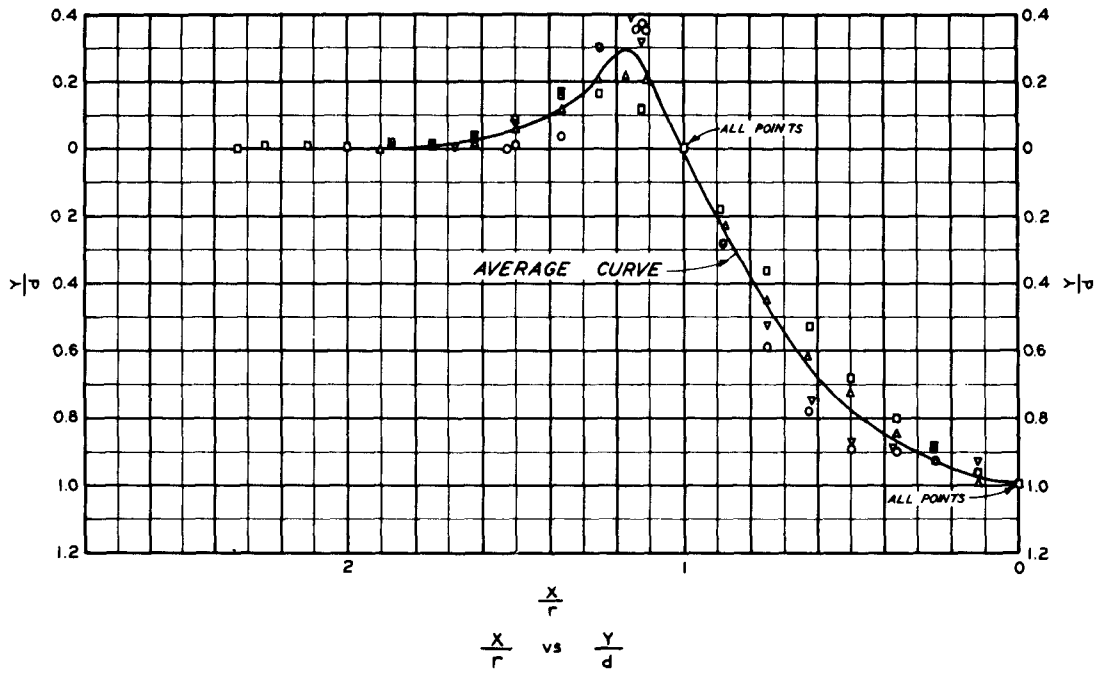
DIMENSIONLESS PLOTS OF HALF-CRATER PROFILES

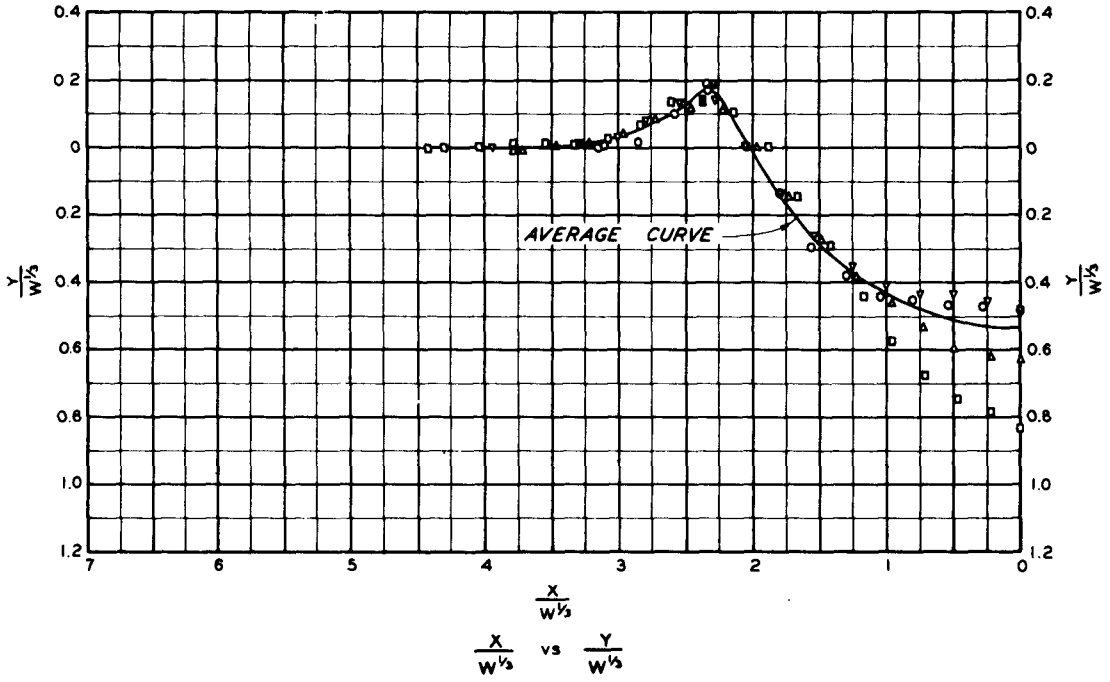
BOTTOM MATERIAL – SAND

CHARGE BELOW BOTTOM (Z = −4.0 D)

$D/W^{\frac{1}{3}} = 0.088$

PLATE 24



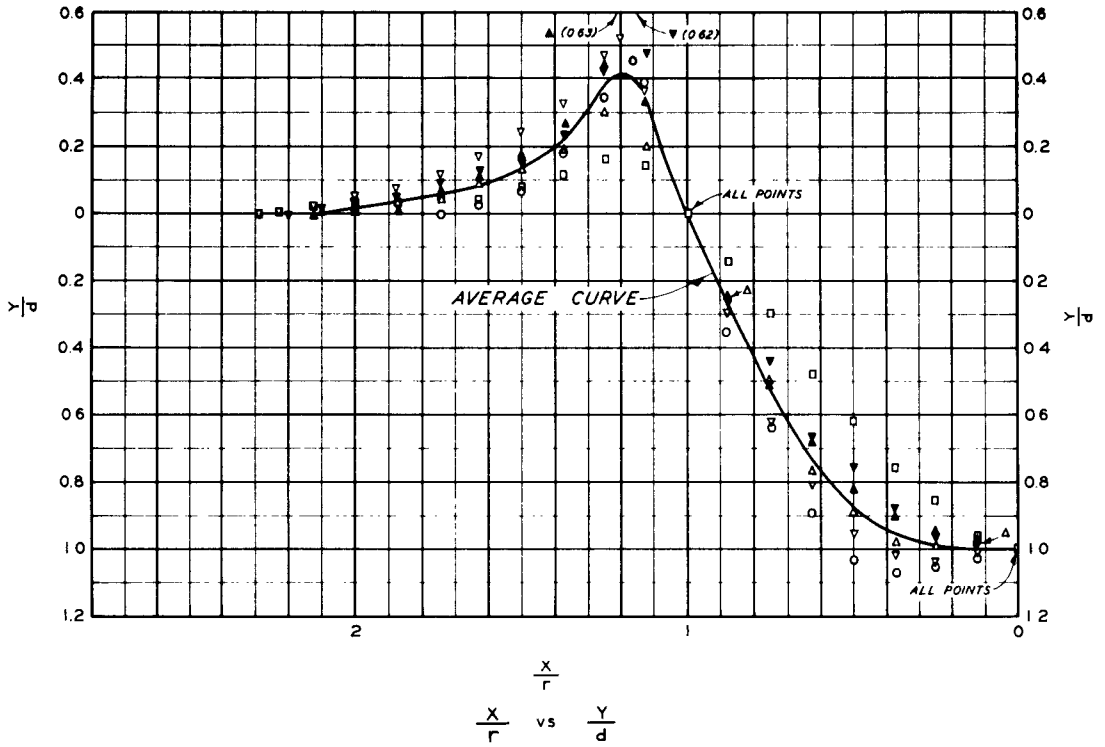


O 32-LB CHARGE
▽ 16-LB CHARGE
△ 4-LB CHARGE
□ 0.5-LB CHARGE

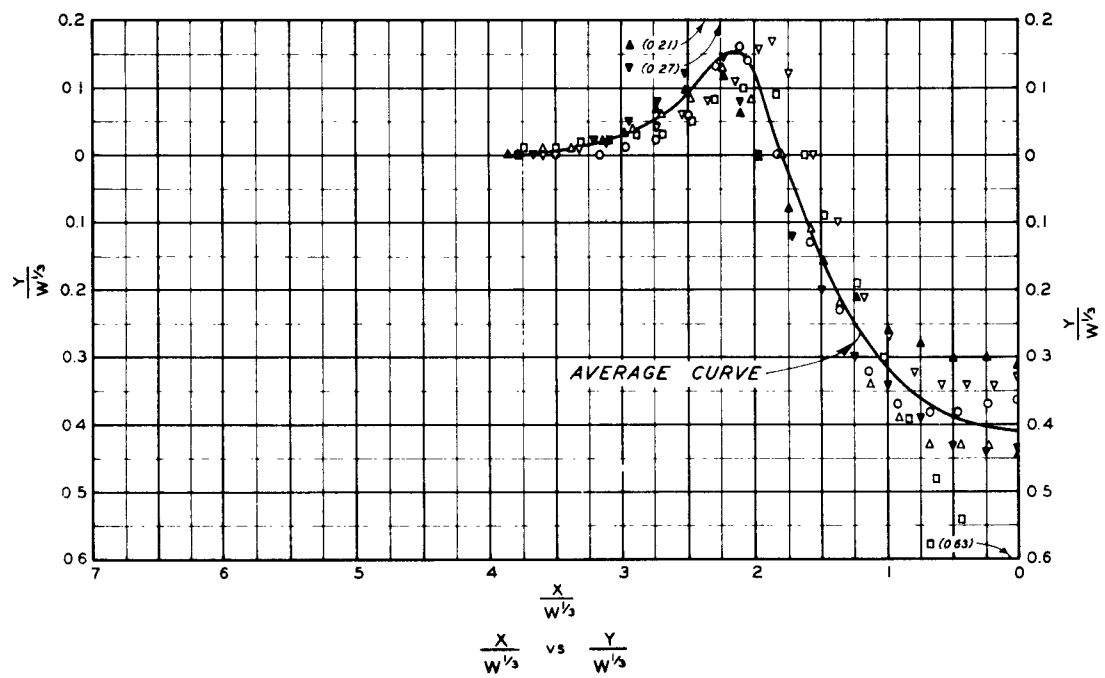
DIMENSIONLESS PLOTS OF HALF-CRATER PROFILES

BOTTOM MATERIAL-SAND
CHARGE BELOW BOTTOM (Z=-2.5 D)
$D/W^{\frac{1}{3}} = 0.088$

PLATE 25



$\frac{X}{r}$ vs $\frac{Y}{d}$



$\frac{X}{W^{1/3}}$ vs $\frac{Y}{W^{1/3}}$

▲ 2048-LB CHARGE
▼ 256-LB CHARGE
○ 32-LB CHARGE
▽ 16-LB CHARGE
△ 4-LB CHARGE
□ 1/2-LB CHARGE

DIMENSIONLESS PLOTS OF HALF-CRATER PROFILES

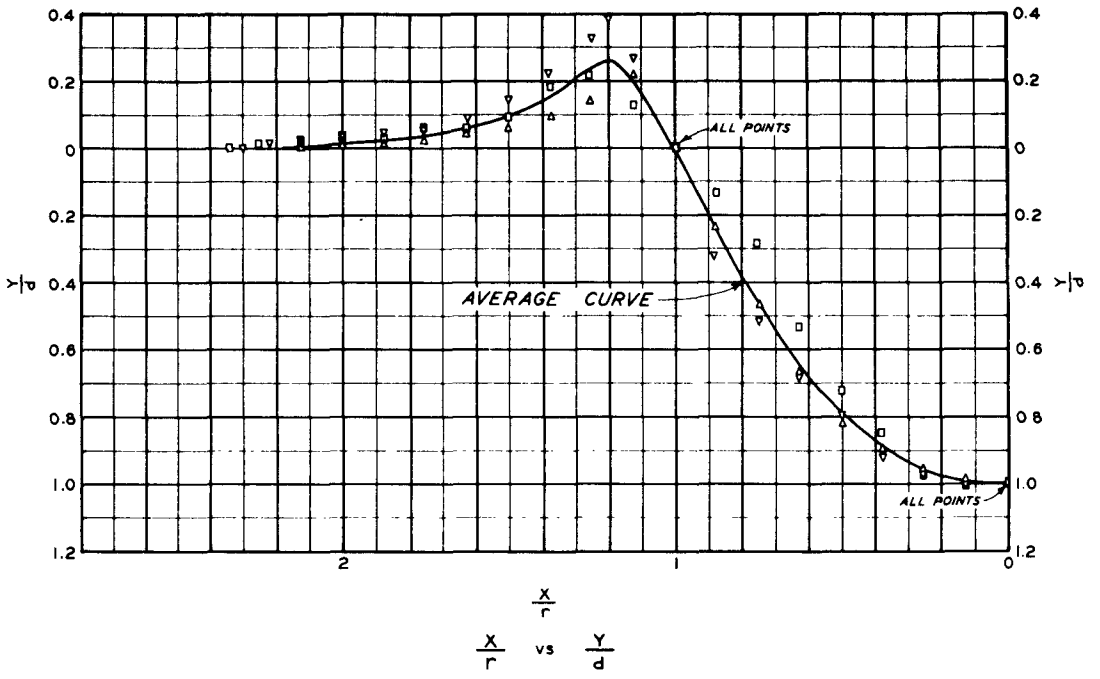
(PRESENTS RESULTS OF FIELD TESTS)

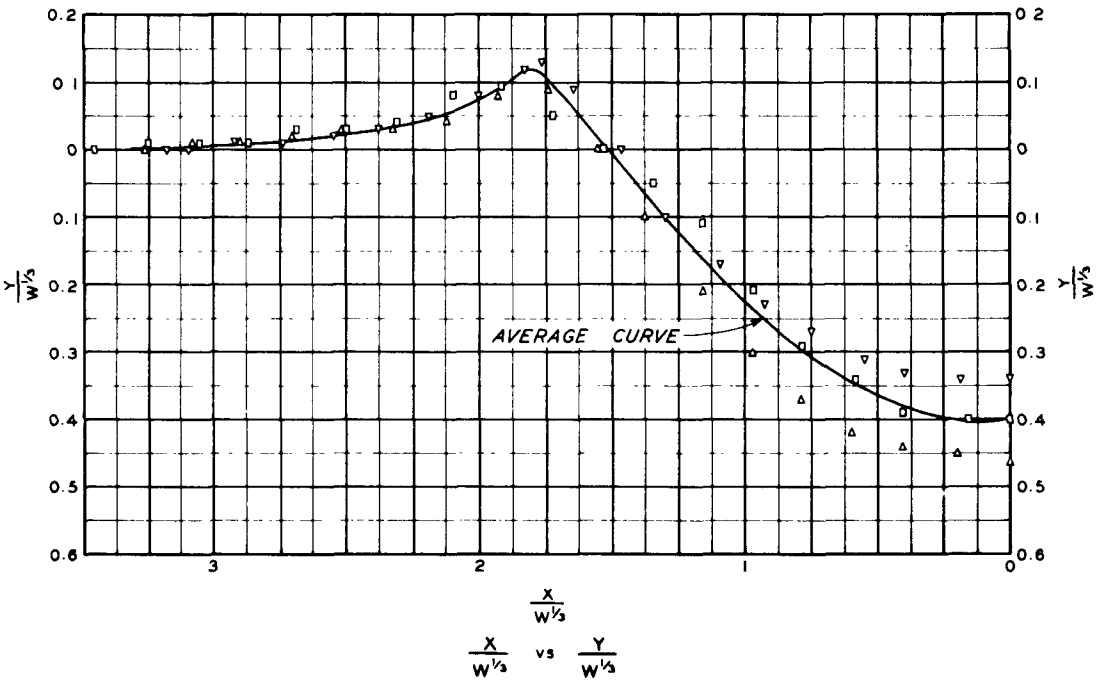
BOTTOM MATERIAL-SAND

CHARGE AT BOTTOM (Z=-1.0 D)

$D/W^{\frac{1}{3}} = 0.088$

PLATE 26





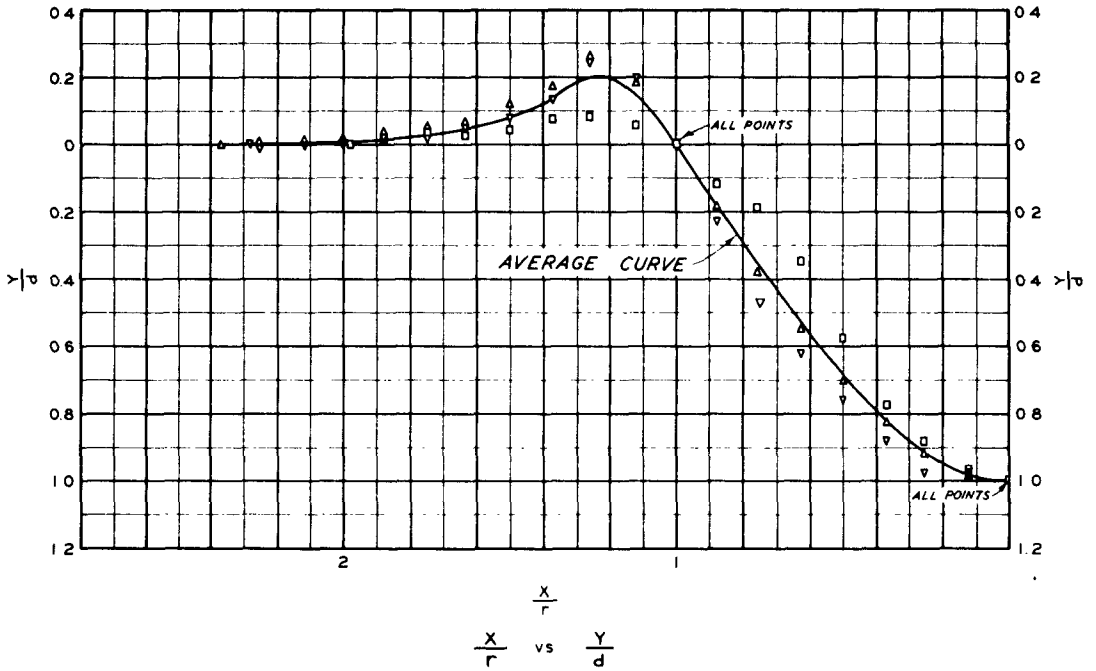
▽ 16-LB CHARGE
△ 4-LB CHARGE
□ 0.5-LB CHARGE

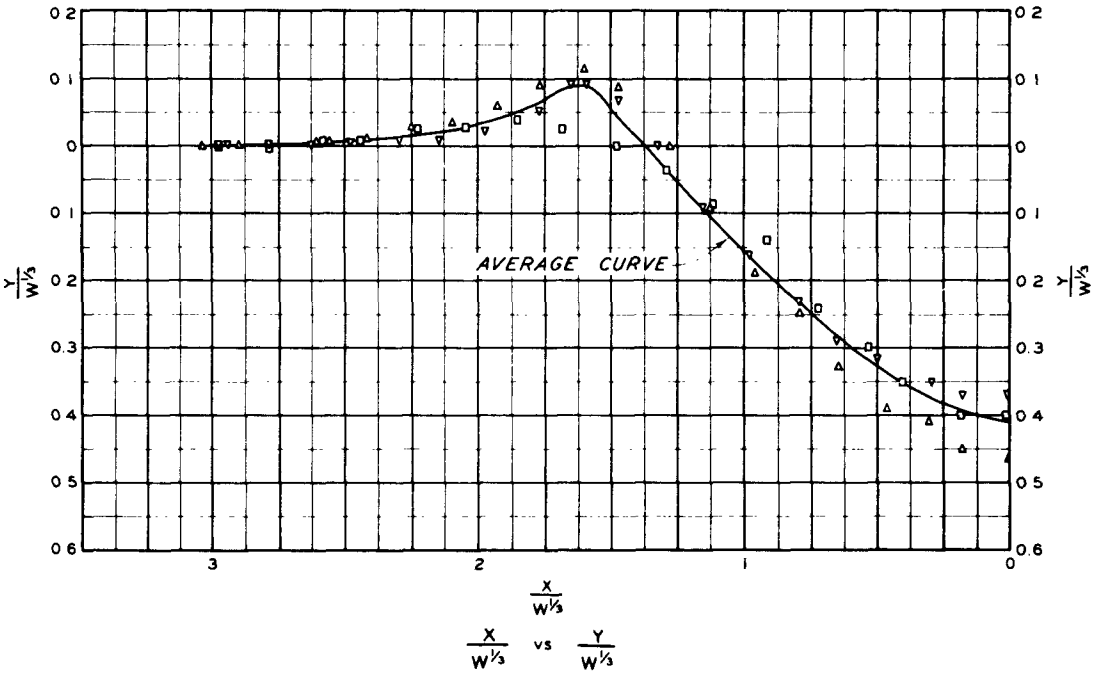
DIMENSIONLESS PLOTS OF HALF-CRATER PROFILES

BOTTOM MATERIAL - SAND

CHARGE AT SURFACE (Z = 0)

$D/W^{\frac{1}{3}} = 0.088$



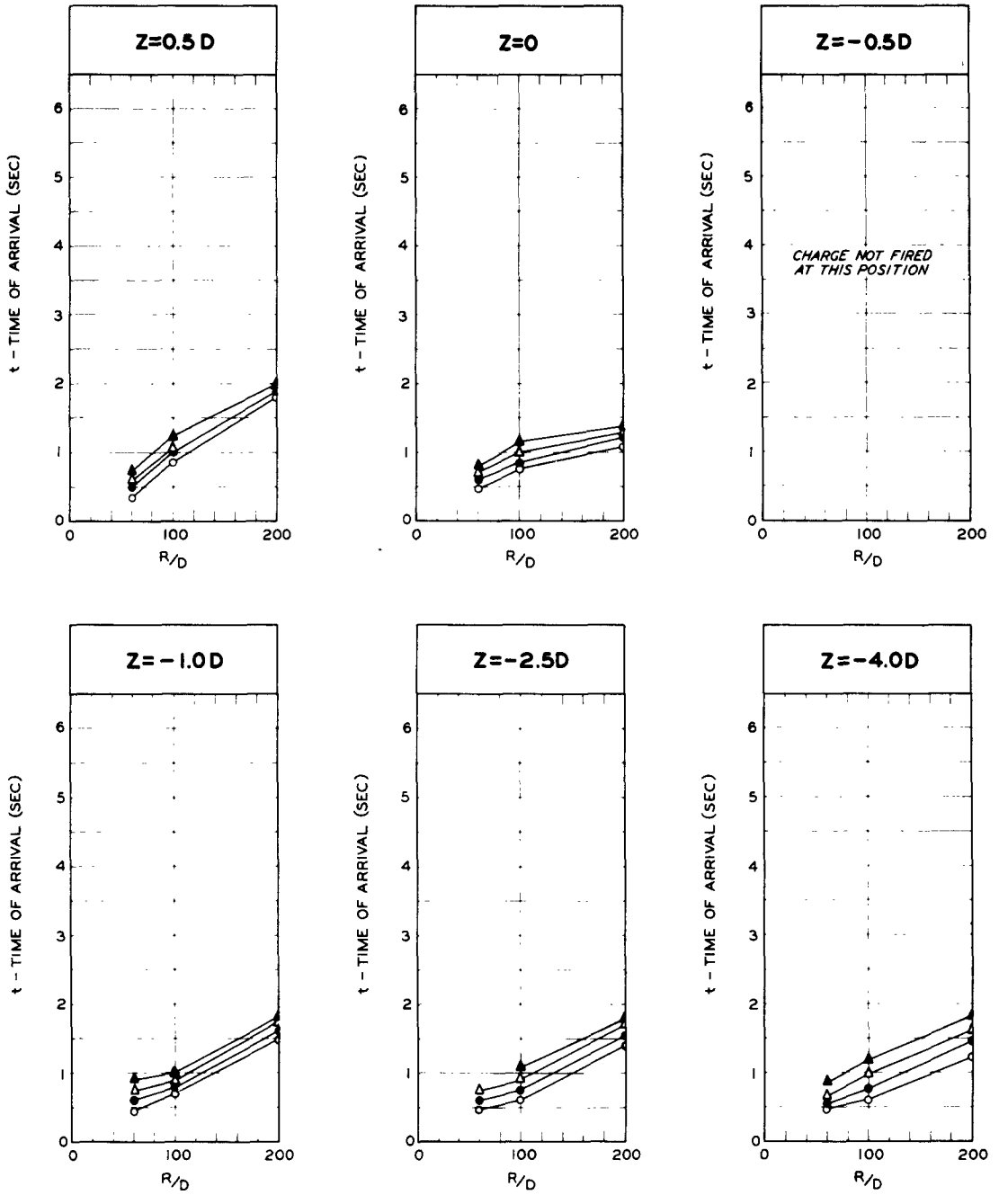


▽ 16-LB CHARGE
△ 4-LB CHARGE
□ 1/2-LB CHARGE

DIMENSIONLESS PLOTS OF HALF-CRATER PROFILES

BOTTOM MATERIAL - SAND
CHARGE ABOVE SURFACE (Z=0.5 D)
$D/W^{\frac{1}{3}} = 0.088$

PLATE 28

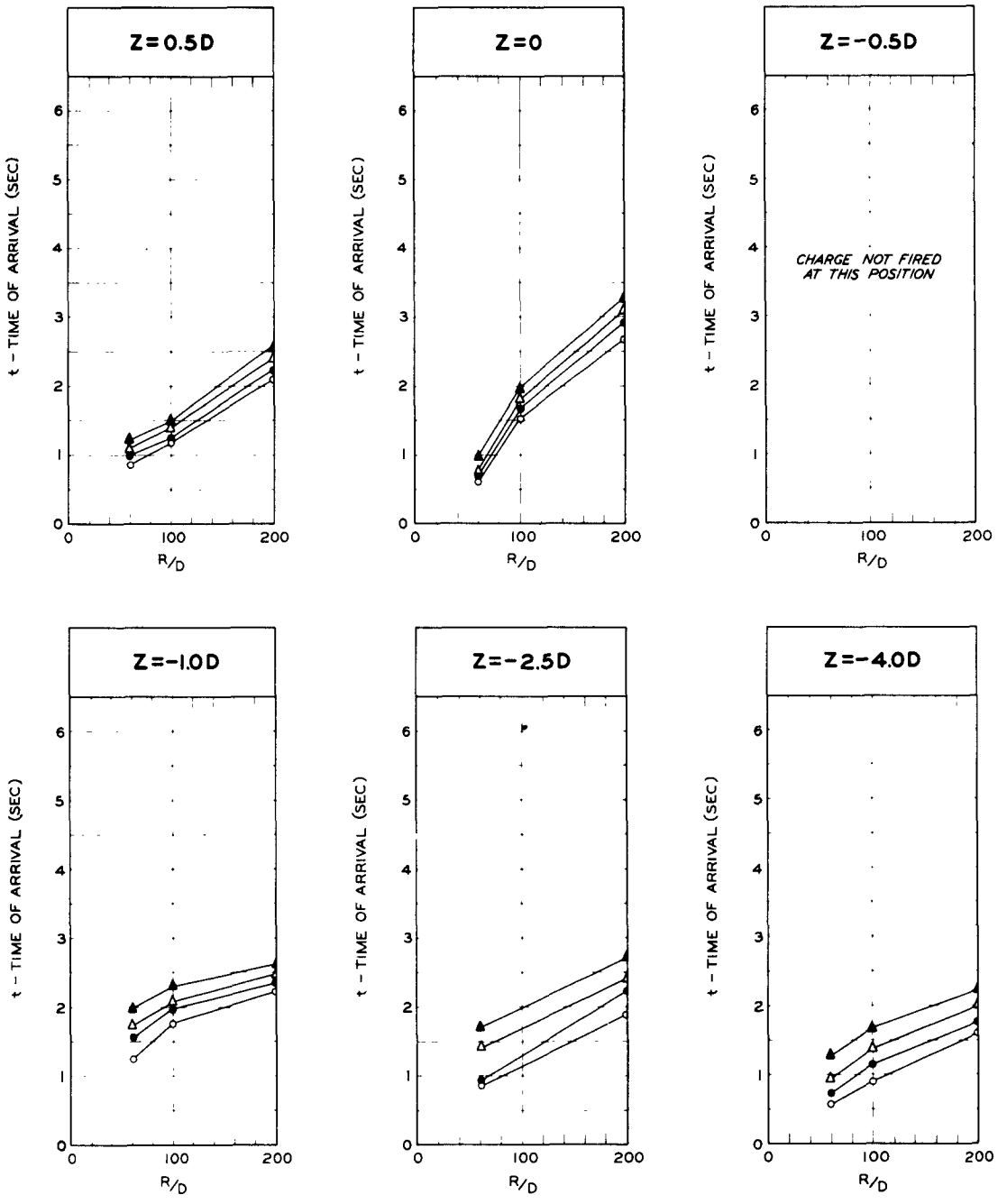


- ○ FIRST WAVE - CREST
- ● FIRST WAVE - TROUGH
- △ SECOND WAVE - CREST
- ▲ SECOND WAVE - TROUGH
- R DISTANCE FROM CHARGE IN FEET
- D DEPTH OF WATER IN FEET
- Z CHARGE POSITION

TIME OF ARRIVAL OF SURFACE WAVES

CHARGE WEIGHT = 0.5 LB

$D/W^{\frac{1}{3}} = 0.088$



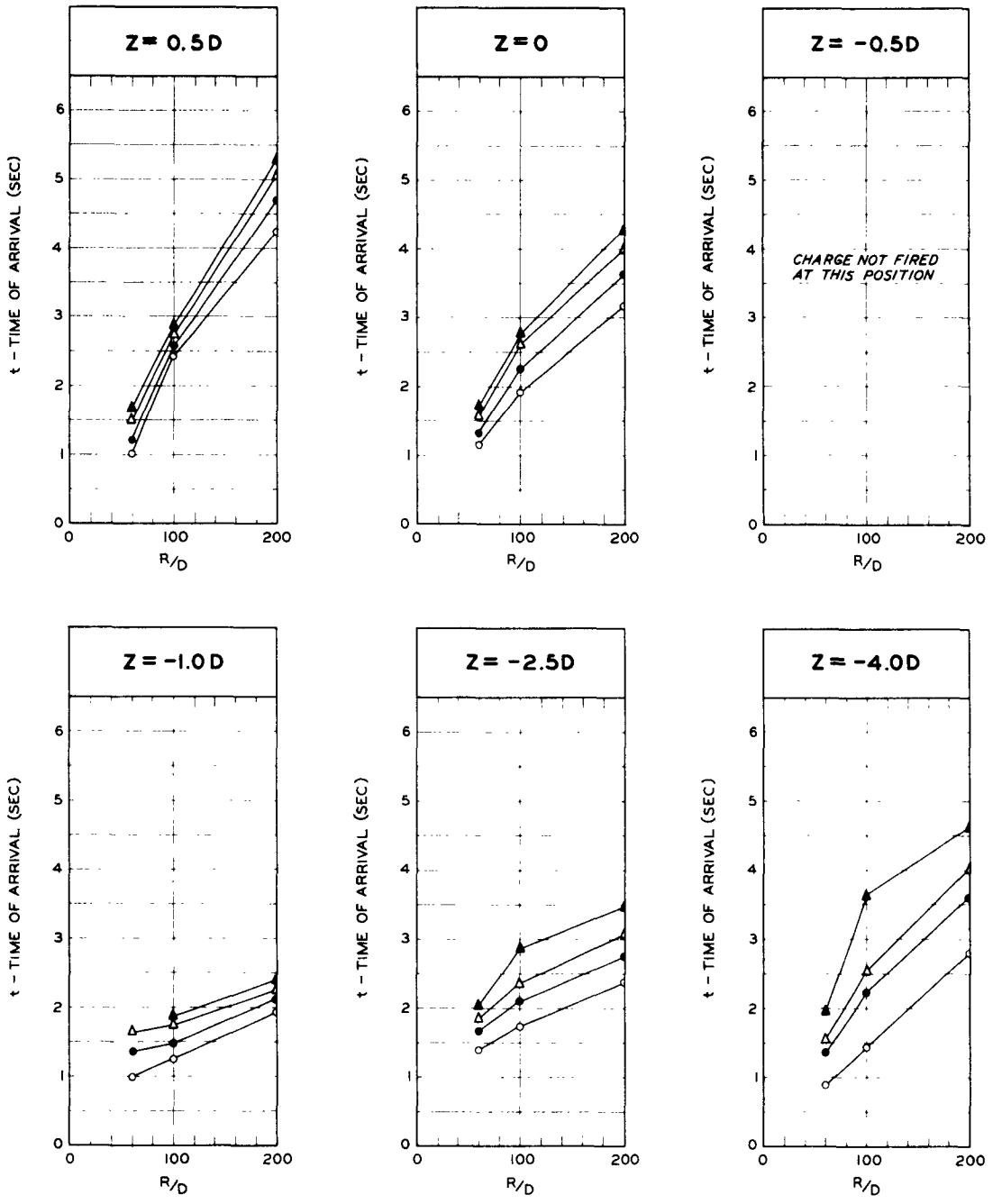
- ○ FIRST WAVE - CREST
- ● FIRST WAVE - TROUGH
- △ SECOND WAVE - CREST
- ▲ SECOND WAVE - TROUGH
- R DISTANCE FROM CHARGE IN FEET
- D DEPTH OF WATER IN FEET
- Z CHARGE POSITION

TIME OF ARRIVAL OF SURFACE WAVES

CHARGE WEIGHT = 4 LB

$D/W^{\frac{1}{3}} = 0.088$

PLATE 30

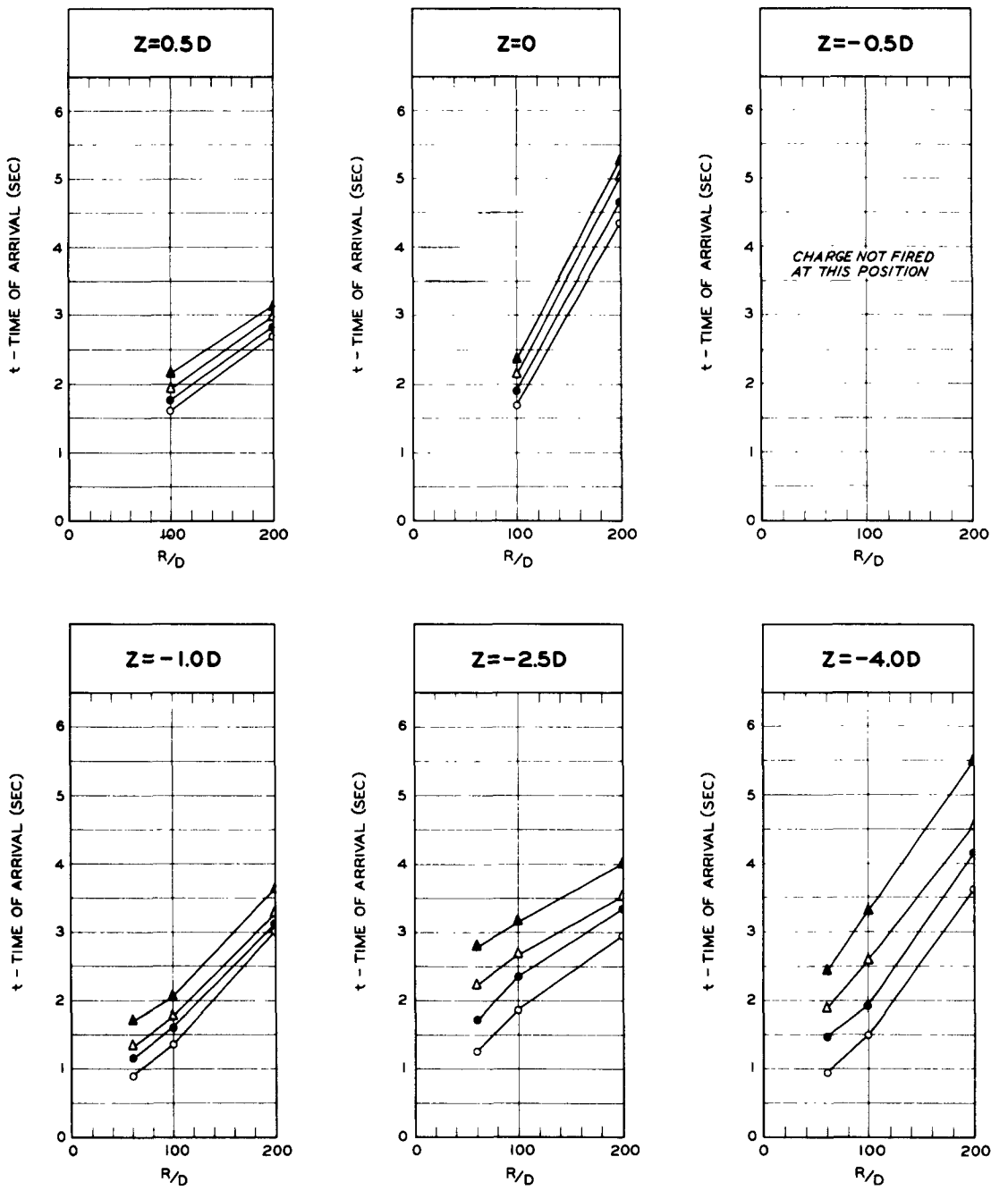


- ○ FIRST WAVE - CREST
- ● FIRST WAVE - TROUGH
- △ SECOND WAVE - CREST
- ▲ SECOND WAVE - TROUGH
- R DISTANCE FROM CHARGE IN FEET
- D DEPTH OF WATER IN FEET
- Z CHARGE POSITION

TIME OF ARRIVAL OF SURFACE WAVES

CHARGE WEIGHT = 16 LB

$D/W^{\frac{1}{3}} = 0.088$



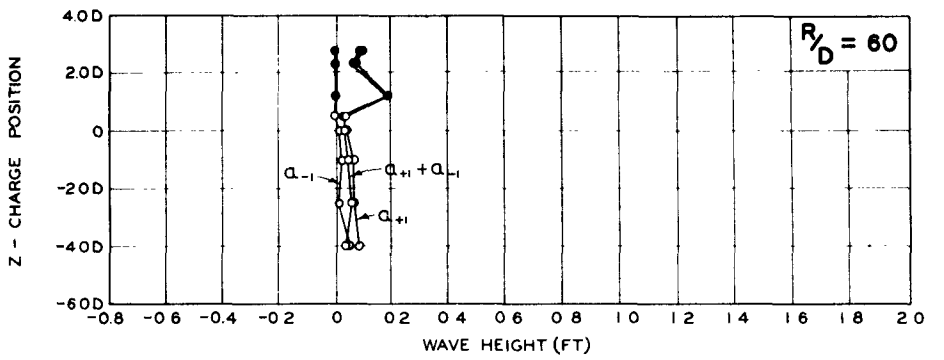
o FIRST WAVE - CREST
● FIRST WAVE - TROUGH
Δ SECOND WAVE - CREST
▲ SECOND WAVE - TROUGH
R DISTANCE FROM CHARGE IN FEET
D DEPTH OF WATER IN FEET
Z CHARGE POSITION

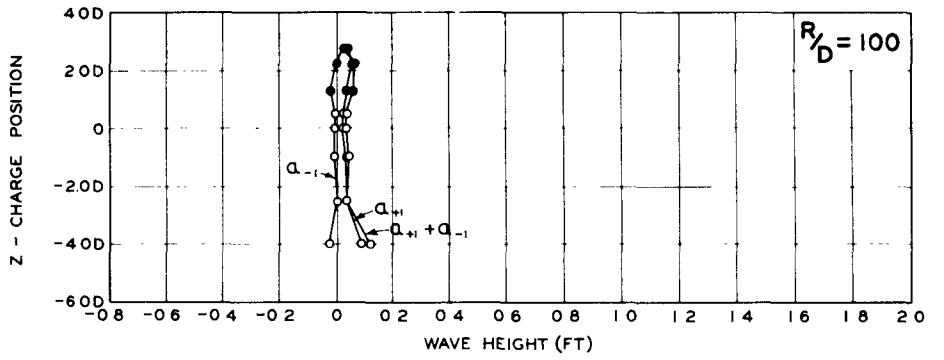
TIME OF ARRIVAL OF SURFACE WAVES

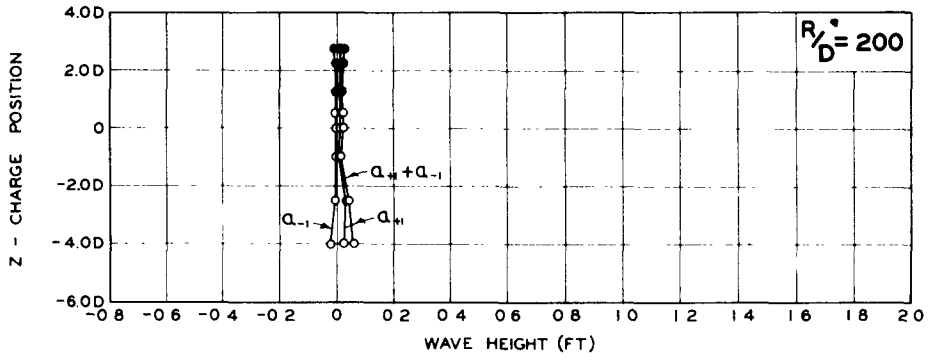
CHARGE WEIGHT = 32 LB

$D/W^{\frac{1}{3}} = 0.088$

PLATE 32







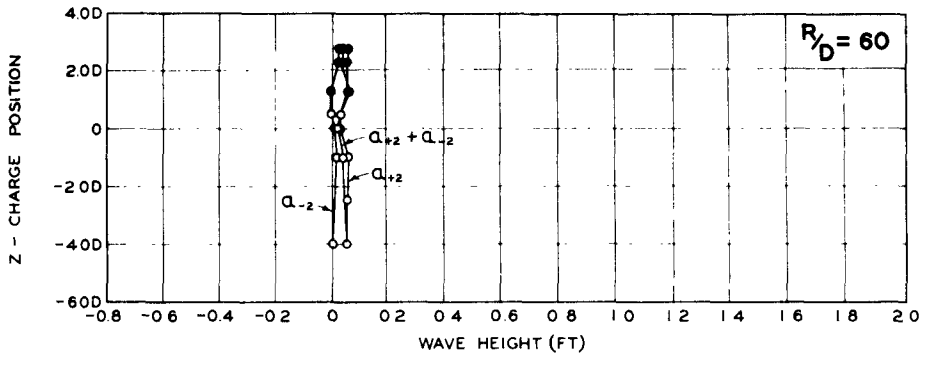
●	BOTTOM MATERIAL - LOESS
O	BOTTOM MATERIAL - SAND
a_{+1}	HEIGHT OF CREST - ABOVE STILL WATER IN FEET
a_{-1}	DEPTH OF TROUGH - BELOW STILL WATER IN FEET
$a_{+1}+a_{-1}$	HEIGHT OF WAVE - CREST TO TROUGH IN FEET
R	DISTANCE FROM CHARGE IN FEET
D	DEPTH OF WATER IN FEET

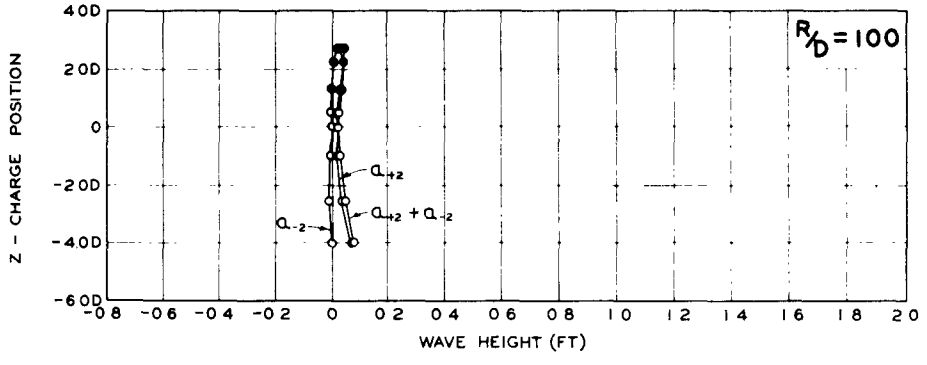
EFFECT OF CHARGE POSITION ON WAVE HEIGHT

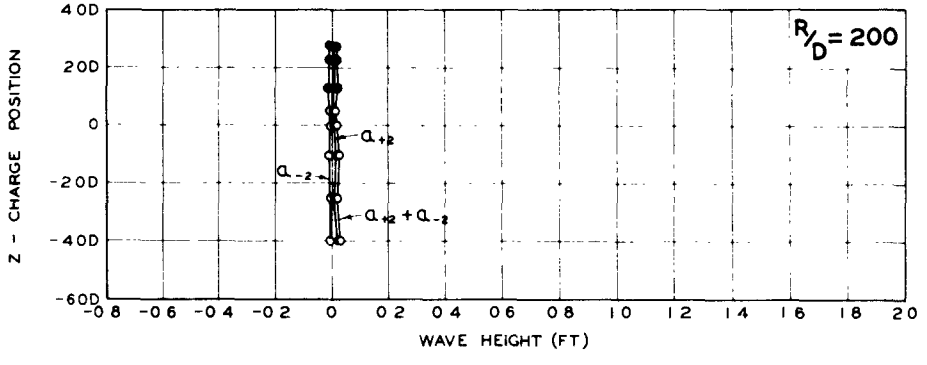
FIRST WAVE

CHARGE WEIGHT = 0.5 LB

$D/W^{\frac{1}{3}} = 0.088$







- ● BOTTOM MATERIAL - LOESS
- O BOTTOM MATERIAL - SAND
- a_{+2} HEIGHT OF CREST - ABOVE STILL WATER IN FEET
- a_{-2} DEPTH OF TROUGH - BELOW STILL WATER IN FEET
- $a_{+2}+a_{-2}$ HEIGHT OF WAVE - CREST TO TROUGH IN FEET
- R DISTANCE FROM CHARGE IN FEET
- D DEPTH OF WATER IN FEET

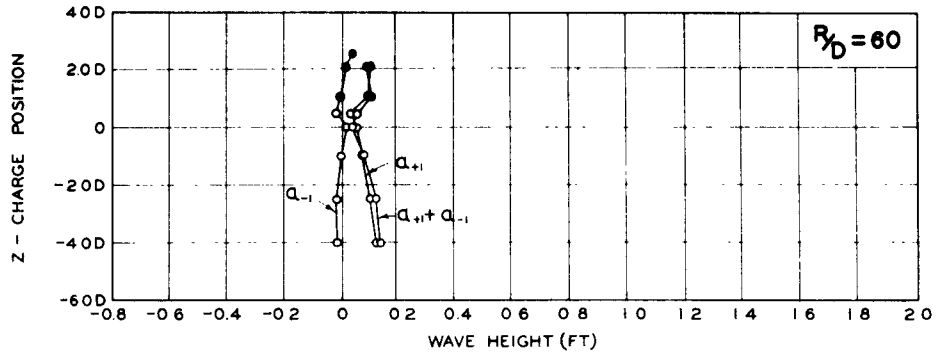
EFFECT OF CHARGE POSITION ON WAVE HEIGHT

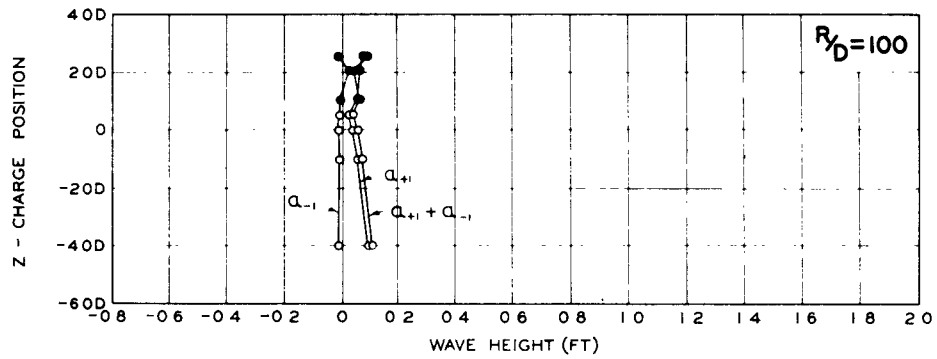
SECOND WAVE

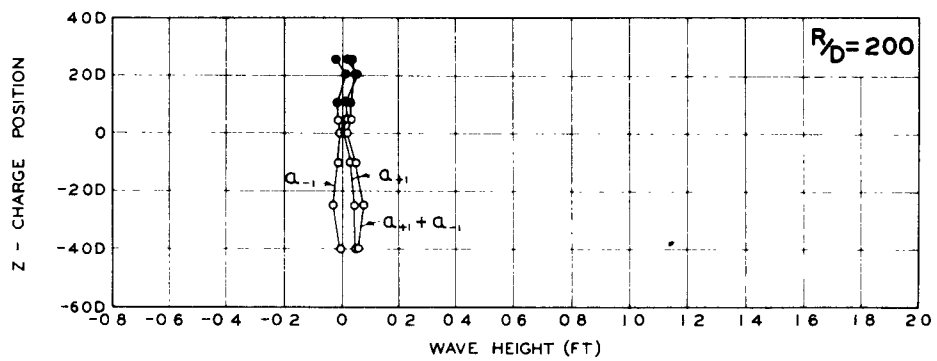
CHARGE WEIGHT = 0.5 LB

$D/W^{\frac{1}{3}} = 0.088$

PLATE 34







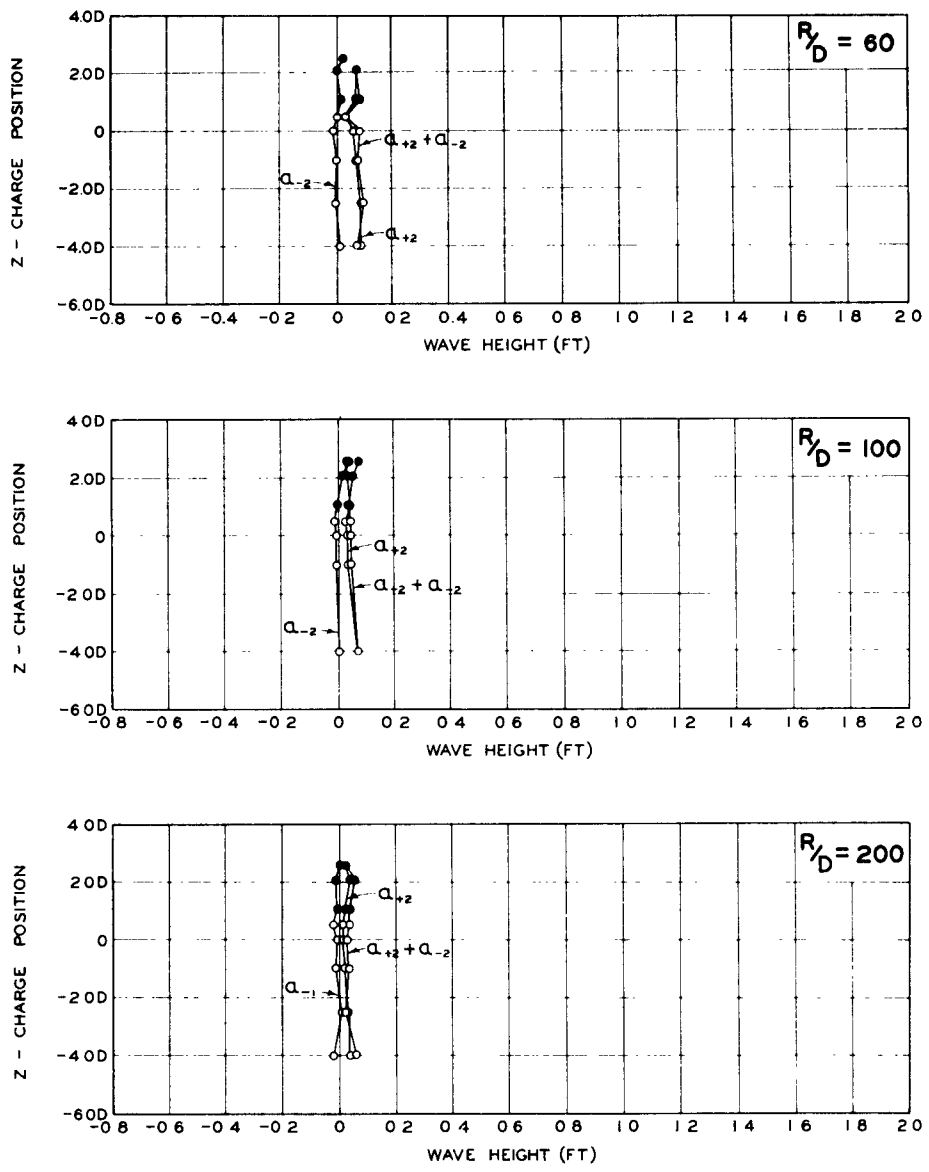
● BOTTOM MATERIAL - LOESS
○ BOTTOM MATERIAL - SAND
a_{+1} HEIGHT OF CREST - ABOVE STILL WATER IN FEET
a_{-1} DEPTH OF TROUGH - BELOW STILL WATER IN FEET
$a_{+1}+a_{-1}$ HEIGHT OF WAVE - CREST TO TROUGH IN FEET
R DISTANCE FROM CHARGE IN FEET
D DEPTH OF WATER IN FEET

EFFECT OF CHARGE POSITION ON WAVE HEIGHT

FIRST WAVE

CHARGE WEIGHT = 4 LB

$D/W^{\frac{1}{3}} = 0.088$



- ● BOTTOM MATERIAL - LOESS
- O BOTTOM MATERIAL - SAND
- a_{+2} HEIGHT OF CREST - ABOVE STILL WATER IN FEET
- a_{-2} DEPTH OF TROUGH - BELOW STILL WATER IN FEET
- $a_{+2}+a_{-2}$ HEIGHT OF WAVE - CREST TO TROUGH IN FEET
- R DISTANCE FROM CHARGE IN FEET
- D DEPTH OF WATER IN FEET

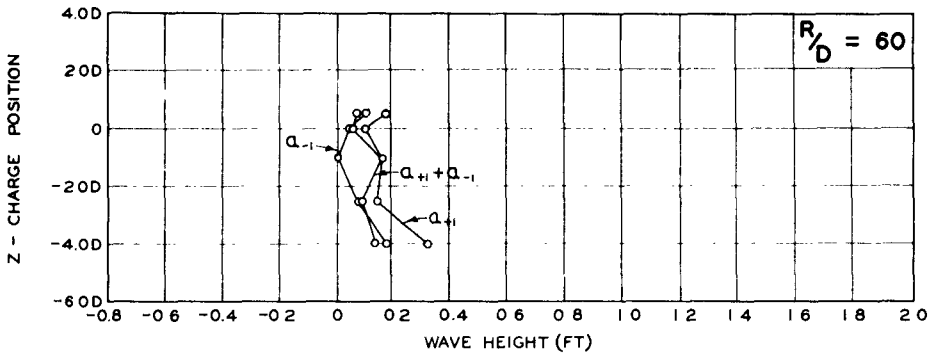
EFFECT OF CHARGE POSITION ON WAVE HEIGHT

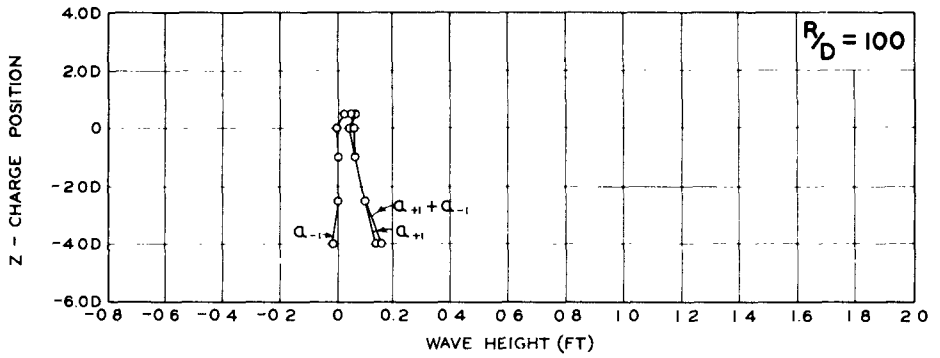
SECOND WAVE

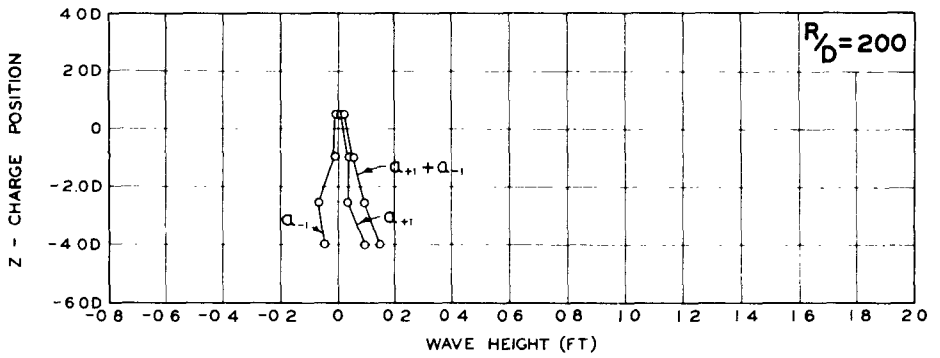
CHARGE WEIGHT = 4 LB

$D/W^{\frac{1}{3}} = 0.088$

PLATE 36







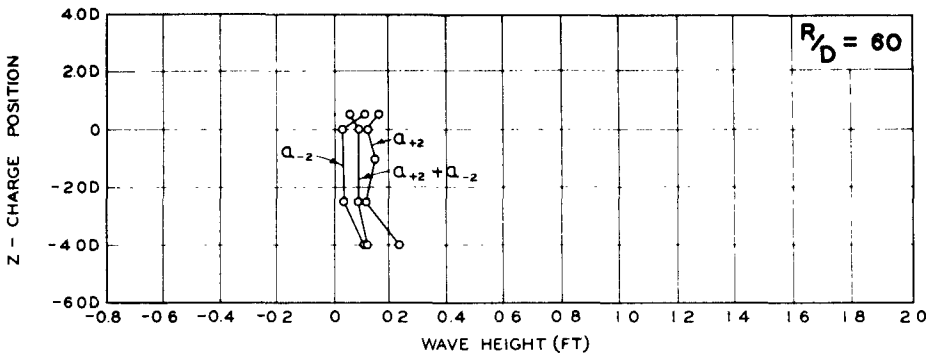
a_{+1}	HEIGHT OF CREST – ABOVE STILL WATER IN FEET
a_{-1}	DEPTH OF TROUGH – BELOW STILL WATER IN FEET
$a_{+1}+a_{-1}$	HEIGHT OF WAVE – CREST TO TROUGH IN FEET
R	DISTANCE FROM CHARGE IN FEET
D	DEPTH OF WATER IN FEET

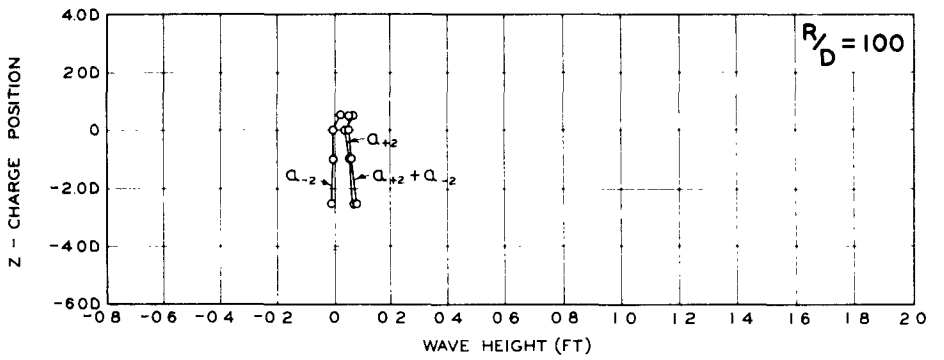
EFFECT OF CHARGE POSITION ON WAVE HEIGHT

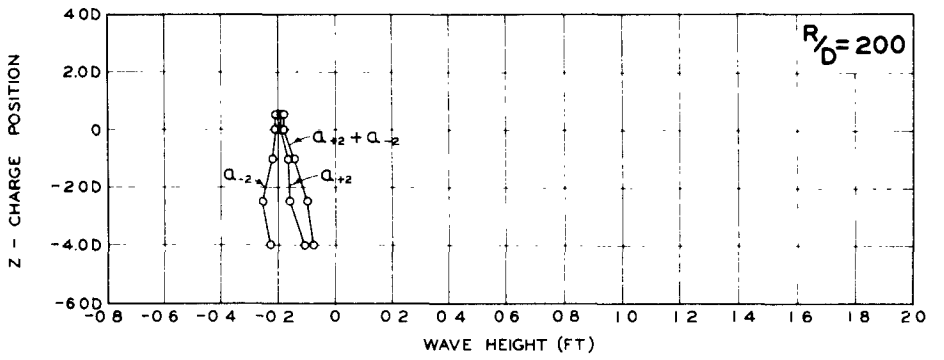
FIRST WAVE

CHARGE WEIGHT = 16 LB

$D/W^{\frac{1}{3}} = 0.088$







a_{+2} HEIGHT OF CREST - ABOVE STILL WATER IN FEET
a_{-2} DEPTH OF TROUGH - BELOW STILL WATER IN FEET
$a_{+2}+a_{-2}$ HEIGHT OF WAVE - CREST TO TROUGH IN FEET
R DISTANCE FROM CHARGE IN FEET
D DEPTH OF WATER IN FEET

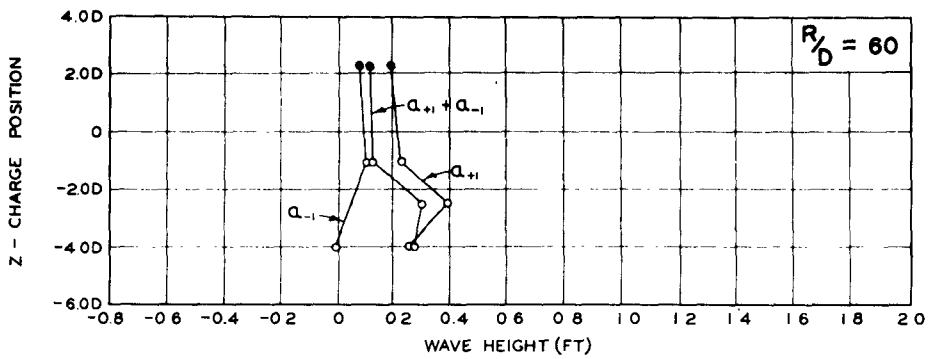
EFFECT OF CHARGE POSITION ON WAVE HEIGHT

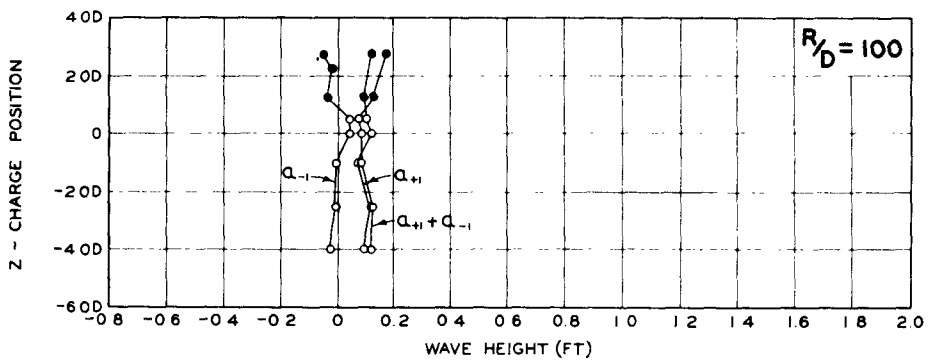
SECOND WAVE

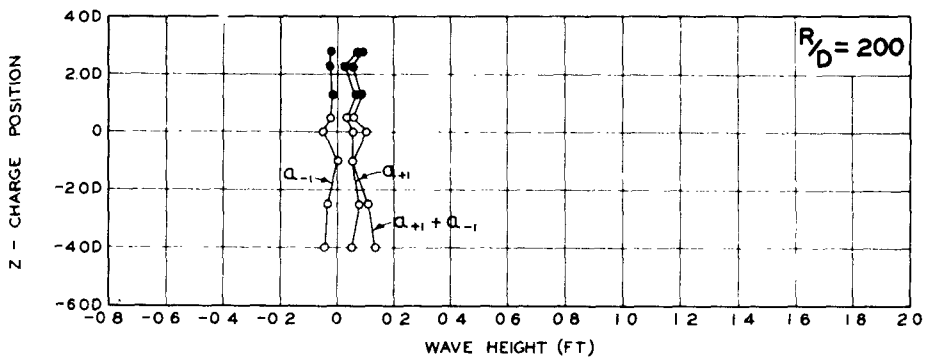
CHARGE WEIGHT = 16 LB

$D/W^{\frac{1}{3}} = 0.088$

PLATE 38







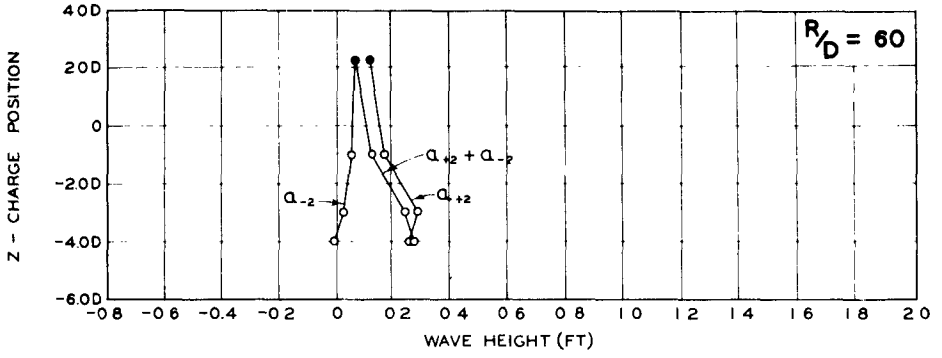
● BOTTOM MATERIAL - LOESS
○ BOTTOM MATERIAL - SAND
a_{+1} HEIGHT OF CREST - ABOVE STILL WATER IN FEET
a_{-1} DEPTH OF TROUGH - BELOW STILL WATER IN FEET
$a_{+1} + a_{-1}$ HEIGHT OF WAVE - CREST TO TROUGH IN FEET
R DISTANCE FROM CHARGE IN FEET
D DEPTH OF WATER IN FEET

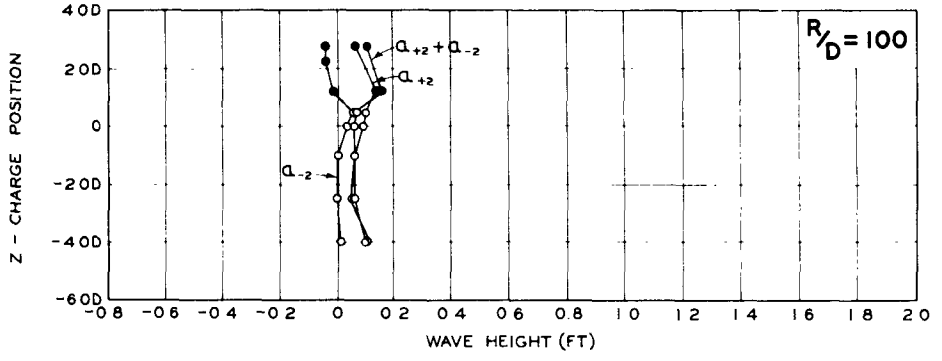
EFFECT OF CHARGE POSITION ON WAVE HEIGHT

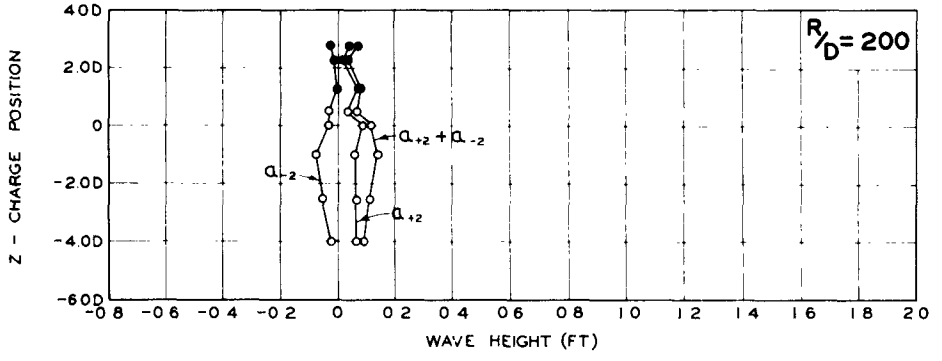
FIRST WAVE

CHARGE WEIGHT = 32 LB

$D/W^{\frac{1}{3}} = 0.088$







●	BOTTOM MATERIAL - LOESS
O	BOTTOM MATERIAL - SAND
a_{+2}	HEIGHT OF CREST - ABOVE STILL WATER IN FEET
a_{-2}	DEPTH OF TROUGH - BELOW STILL WATER IN FEET
$a_{+2}+a_{-2}$	HEIGHT OF WAVE - CREST TO TROUGH IN FEET
R	DISTANCE FROM CHARGE IN FEET
D	DEPTH OF WATER IN FEET

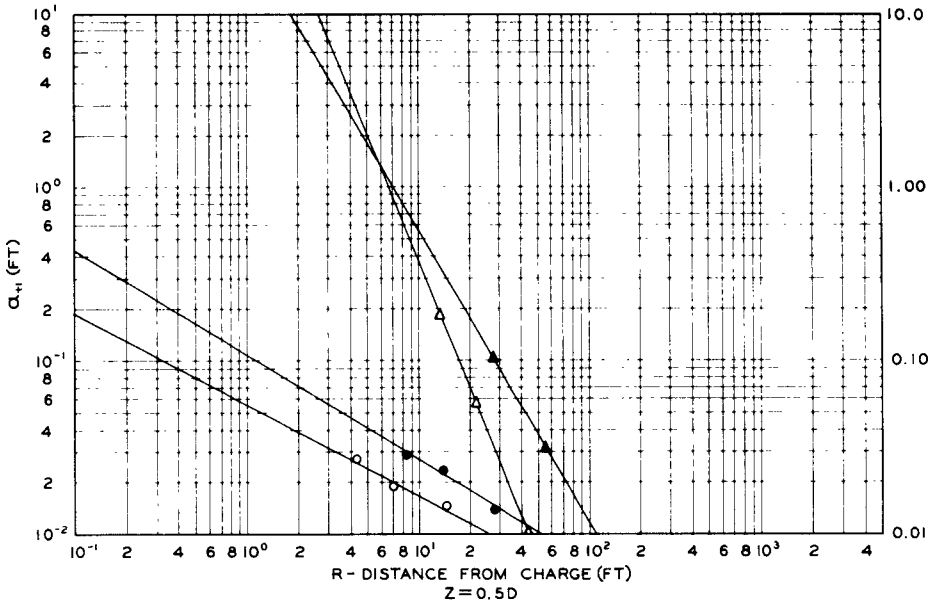
EFFECT OF CHARGE POSITION ON WAVE HEIGHT

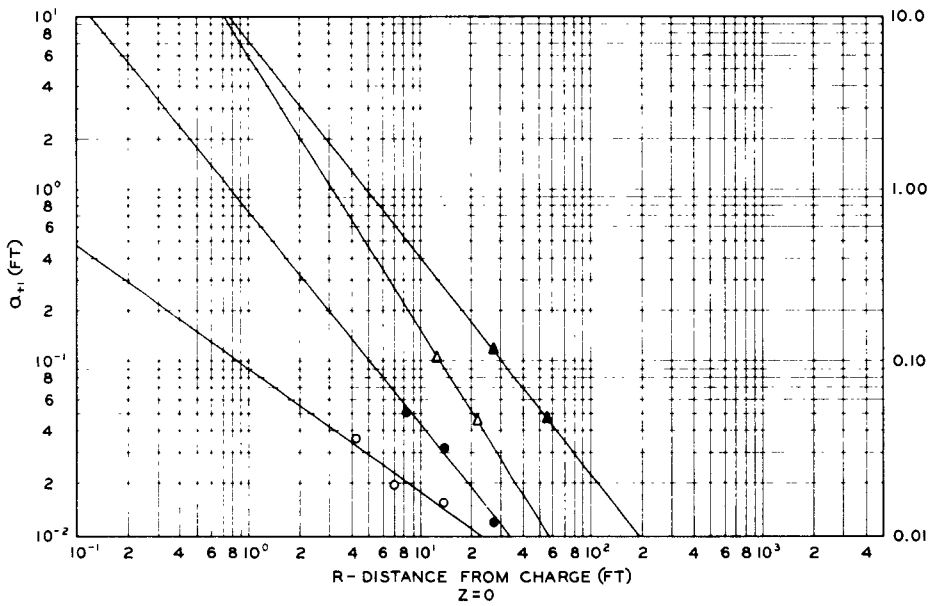
SECOND WAVE

CHARGE WEIGHT = 32 LB

$D/W^{\frac{1}{3}} = 0.088$

PLATE 40



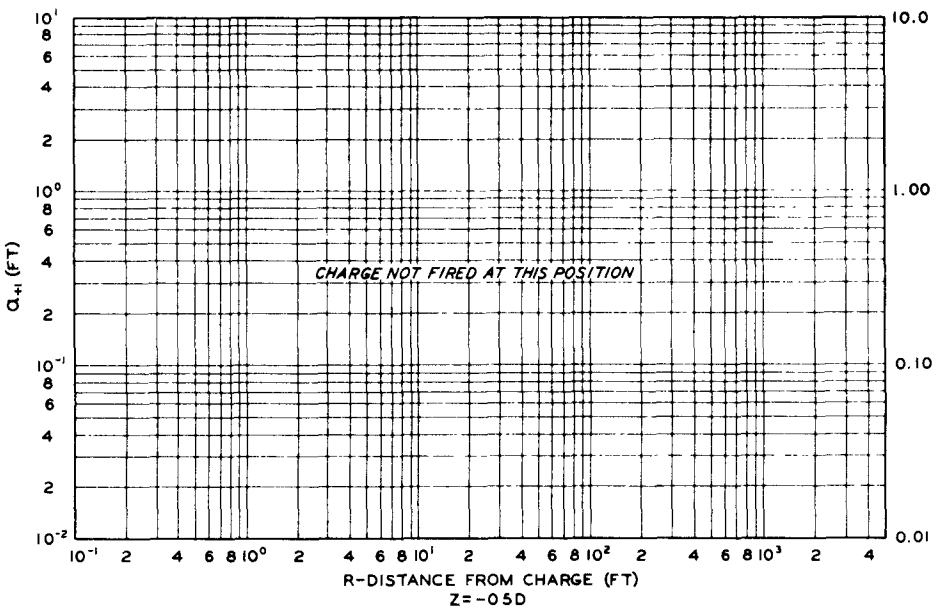


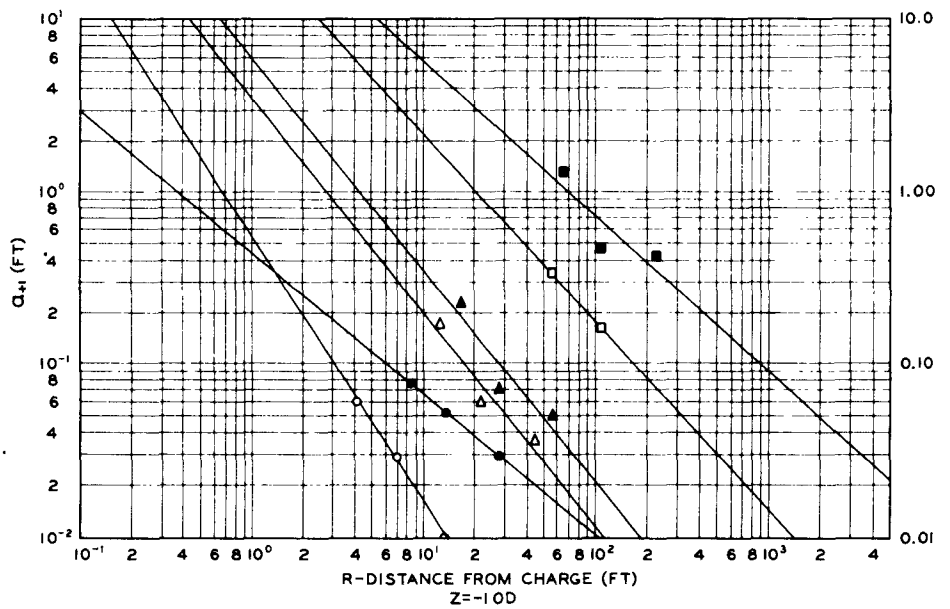
O 0.5-LB CHARGE
● 4-LB CHARGE
Δ 16-LB CHARGE
▲ 32-LB CHARGE
a_{+1} HEIGHT OF CREST ABOVE STILL WATER IN FEET
D DEPTH OF WATER IN FEET
Z CHARGE POSITION

EFFECT OF DISTANCE ON WAVE HEIGHT

FIRST CREST

$D/W^{\frac{1}{3}} = 0.088$





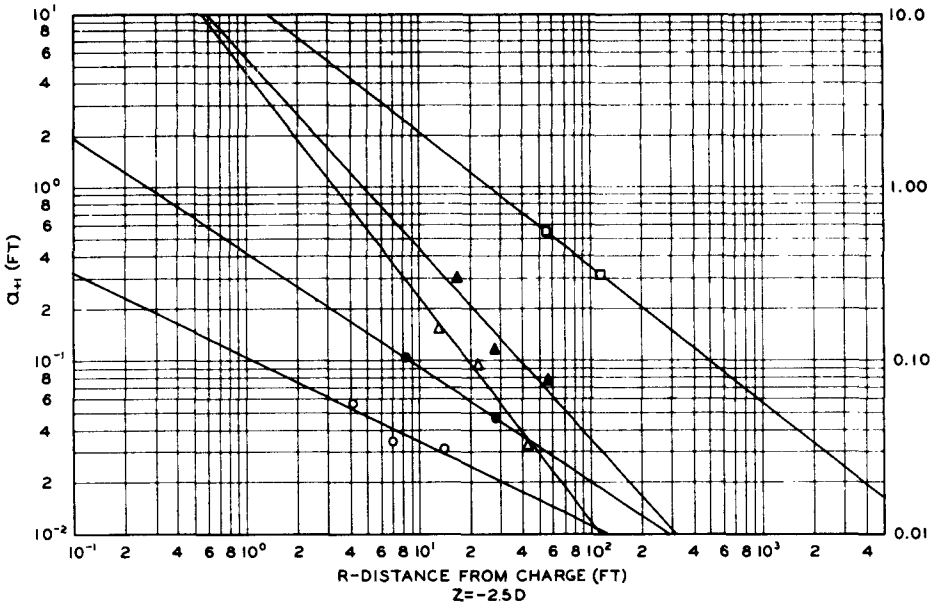
○	05-LB CHARGE
●	4-LB CHARGE
△	16-LB CHARGE
▲	32-LB CHARGE
□	256-LB CHARGE
■	2048-LB CHARGE
a_{+1}	HEIGHT OF CREST ABOVE STILL WATER IN FEET
D	DEPTH OF WATER IN FEET
Z	CHARGE POSITION

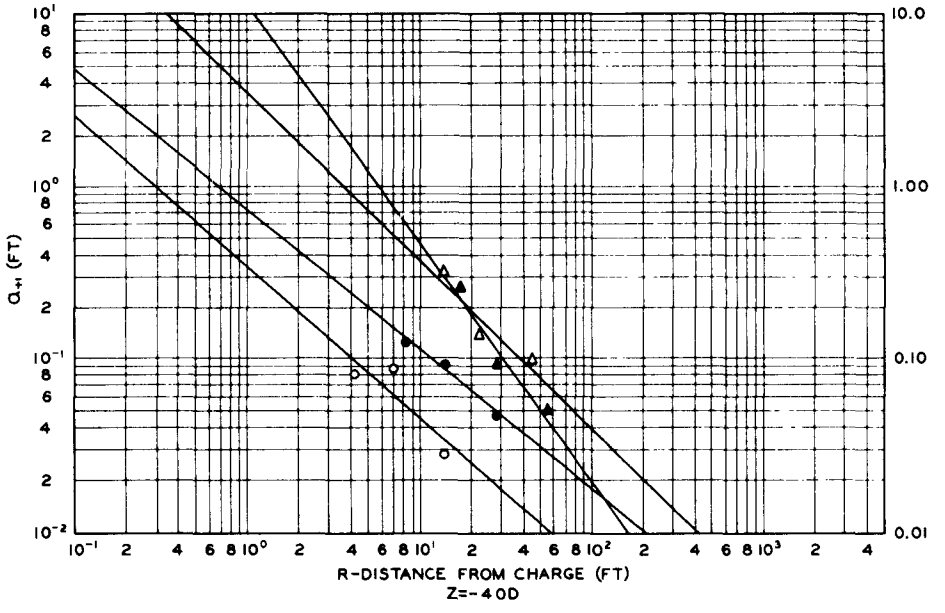
EFFECT OF DISTANCE ON WAVE HEIGHT

FIRST CREST

$D/W^{\frac{1}{3}} = 0.088$

PLATE 42



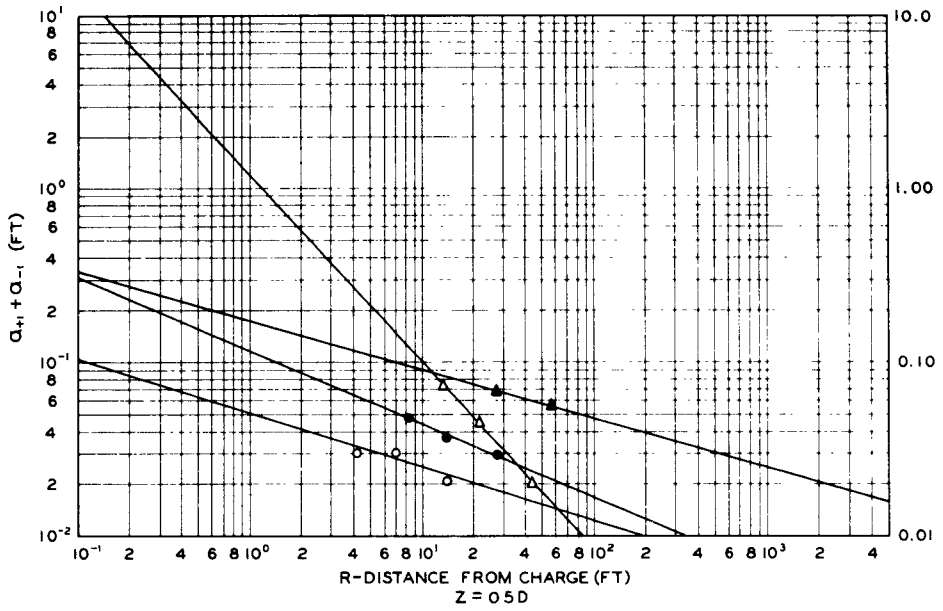


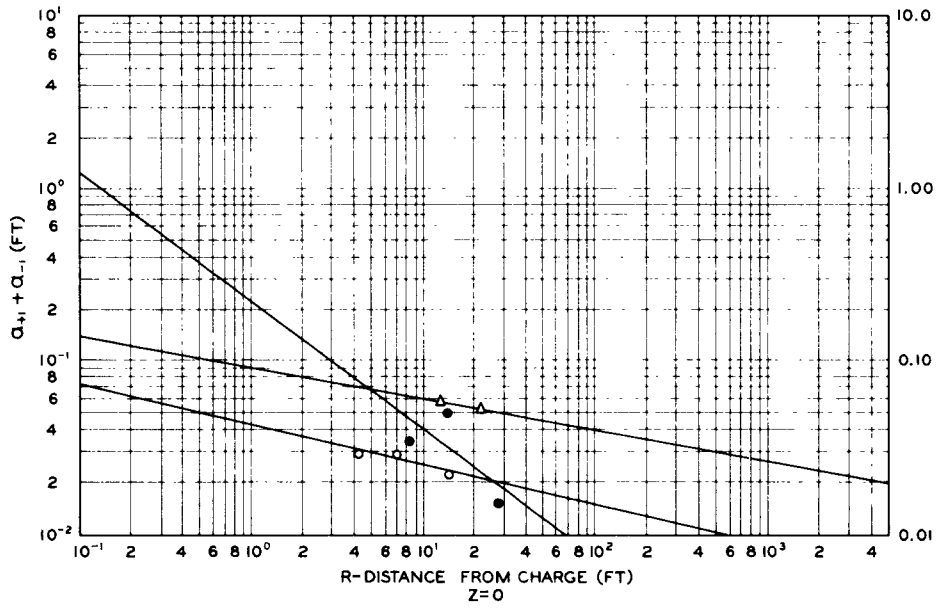
○	0.5-LB CHARGE
●	4-LB CHARGE
△	16-LB CHARGE
▲	32-LB CHARGE
□	256-LB CHARGE
a_{+1}	HEIGHT OF CREST ABOVE STILL WATER IN FEET
D	DEPTH OF WATER IN FEET
Z	CHARGE POSITION

EFFECT OF DISTANCE ON WAVE HEIGHT

FIRST CREST

$D/W^{\frac{1}{3}} = 0.088$





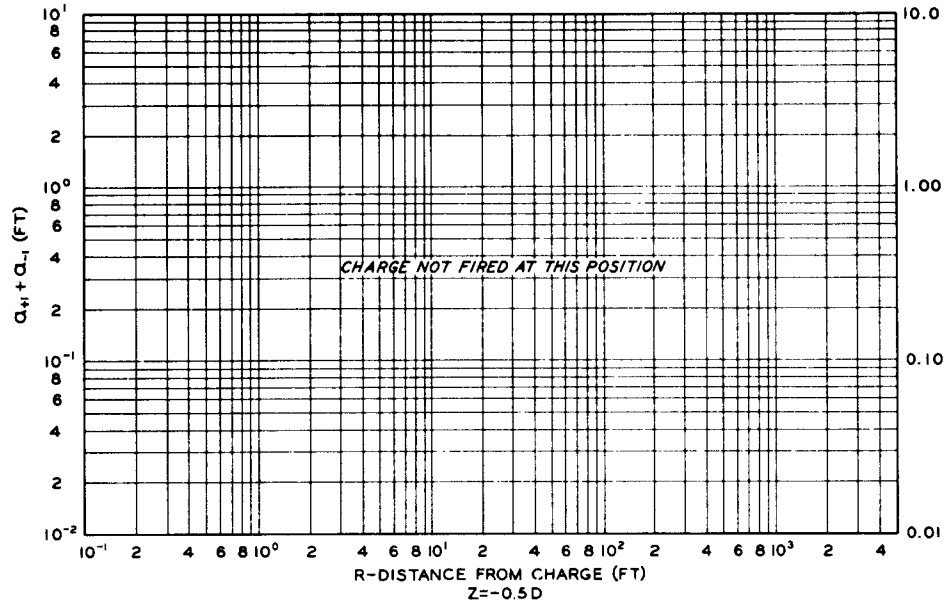
○	0.5-LB CHARGE
●	4-LB CHARGE
△	16-LB CHARGE
▲	32-LB CHARGE
a_{+1}	HEIGHT OF CREST ABOVE STILL WATER IN FEET
a_{-1}	DEPTH OF TROUGH BELOW STILL WATER IN FEET
$a_{+1} + a_{-1}$	HEIGHT OF WAVE-CREST TO TROUGH IN FEET
D	DEPTH OF WATER IN FEET
Z	CHARGE POSITION

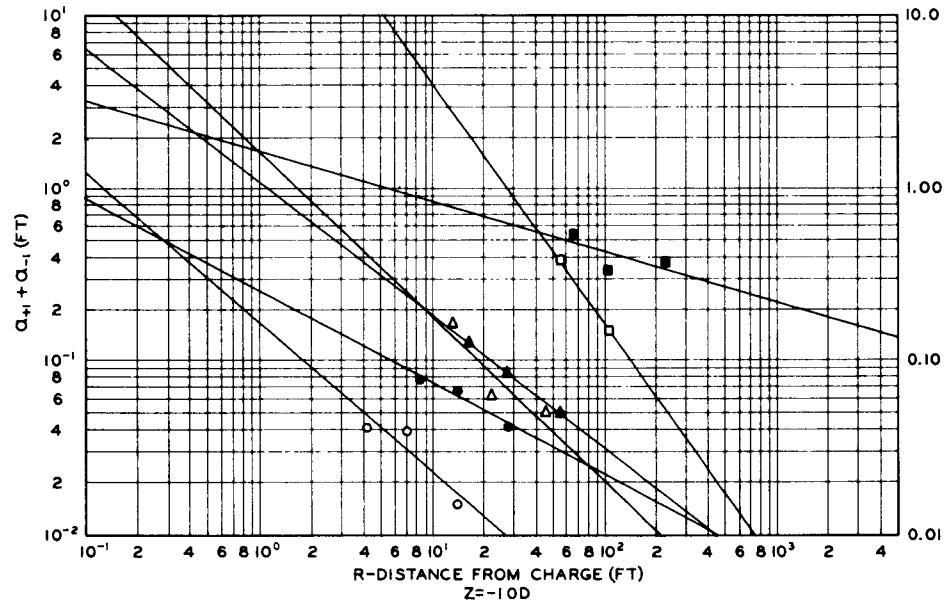
EFFECT OF DISTANCE ON WAVE HEIGHT

FIRST CREST PLUS FIRST TROUGH

$D/W^{\frac{1}{3}} = 0.088$

PLATE 44



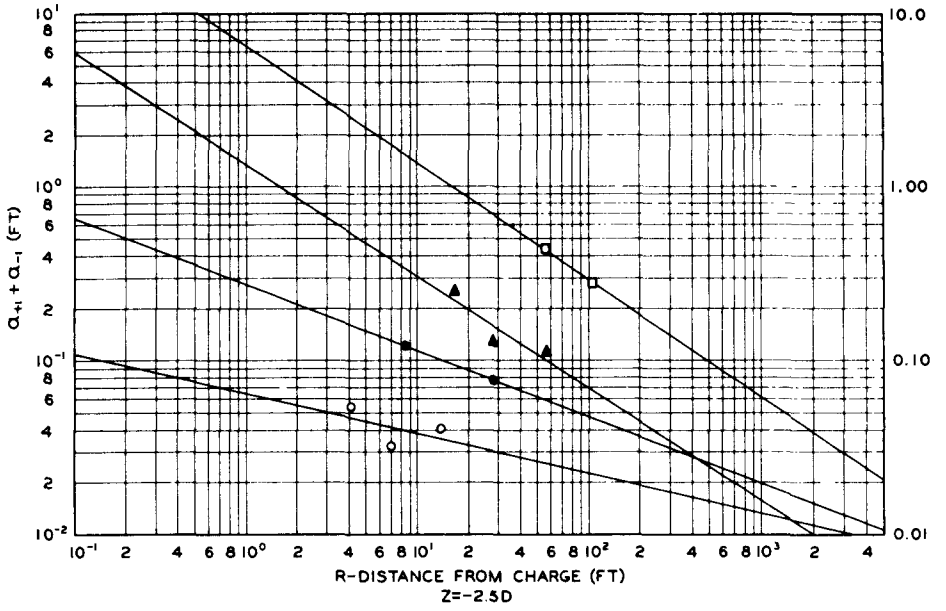


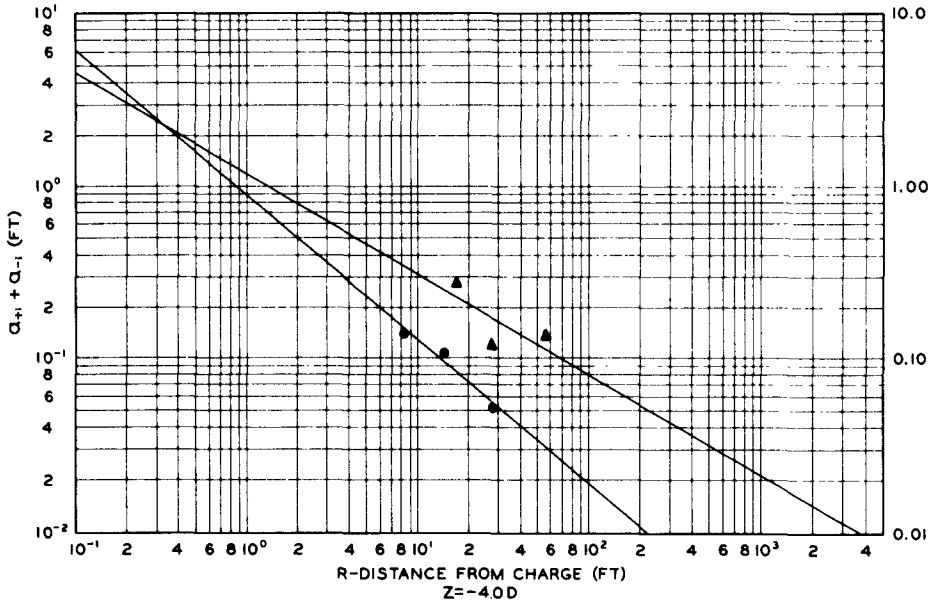
○	0.5-LB CHARGE
●	4-LB CHARGE
△	16-LB CHARGE
▲	32-LB CHARGE
□	256-LB CHARGE
■	2048-LB CHARGE
a_{+1}	HEIGHT OF CREST ABOVE STILL WATER IN FEET
a_{-1}	DEPTH OF TROUGH BELOW STILL WATER IN FEET
$a_{+1} + a_{-1}$	HEIGHT OF WAVE-CREST TO TROUGH IN FEET
D	DEPTH OF WATER IN FEET
Z	CHARGE POSITION

EFFECT OF DISTANCE ON WAVE HEIGHT

FIRST CREST PLUS FIRST TROUGH

$D/W^{\frac{1}{3}} = 0.088$





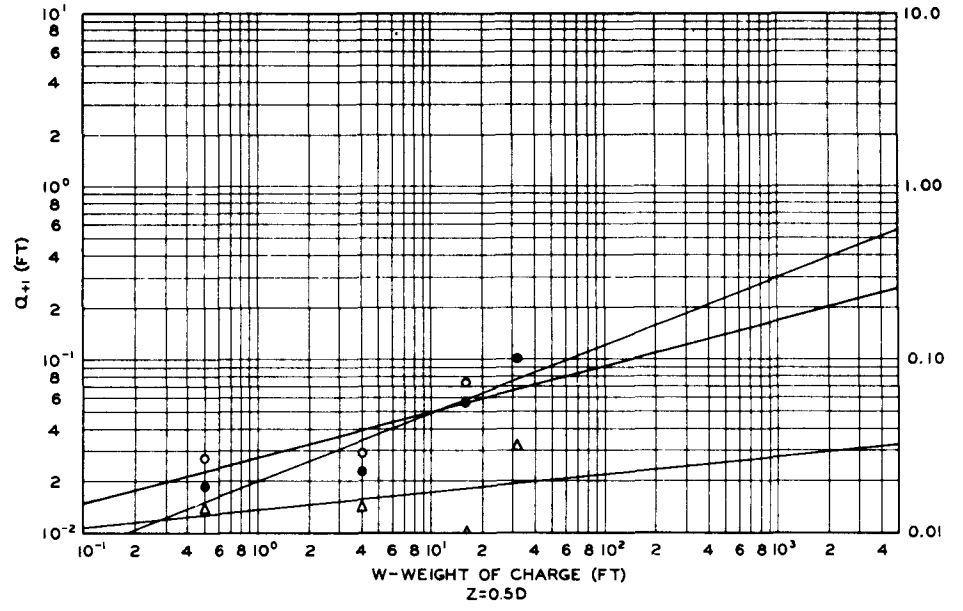
○	05-LB CHARGE
●	4-LB CHARGE
▲	32-LB CHARGE
□	256-LB CHARGE
a_{+1}	HEIGHT OF CREST ABOVE STILL WATER IN FEET
a_{-1}	DEPTH OF TROUGH BELOW STILL WATER IN FEET
$a_{+1} + a_{-1}$	HEIGHT OF WAVE-CREST TO TROUGH IN FEET
D	DEPTH OF WATER IN FEET
Z	CHARGE POSITION

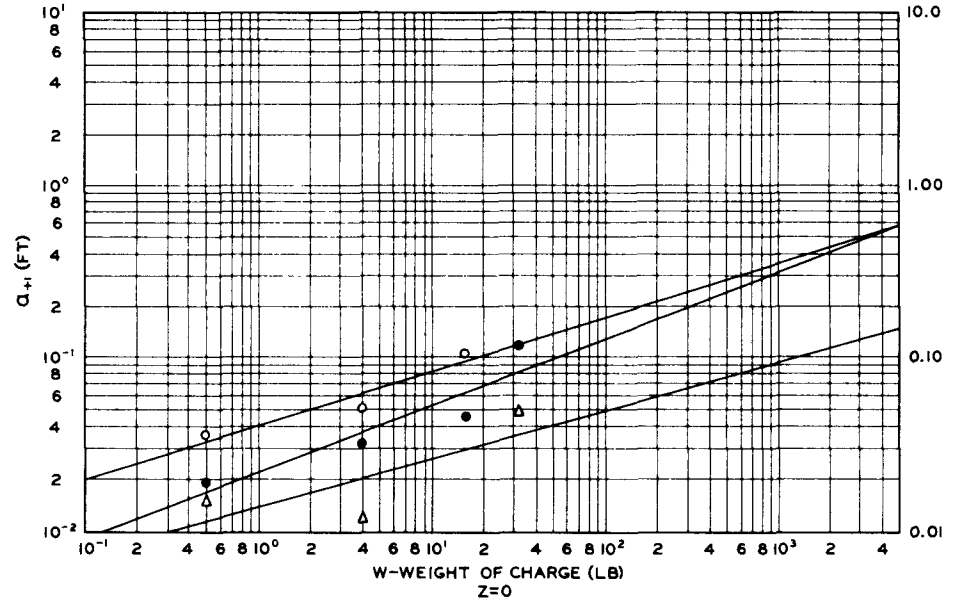
EFFECT OF DISTANCE ON WAVE HEIGHT

FIRST CREST PLUS FIRST TROUGH

$D/W^{\frac{1}{3}} = 0.088$

PLATE 46



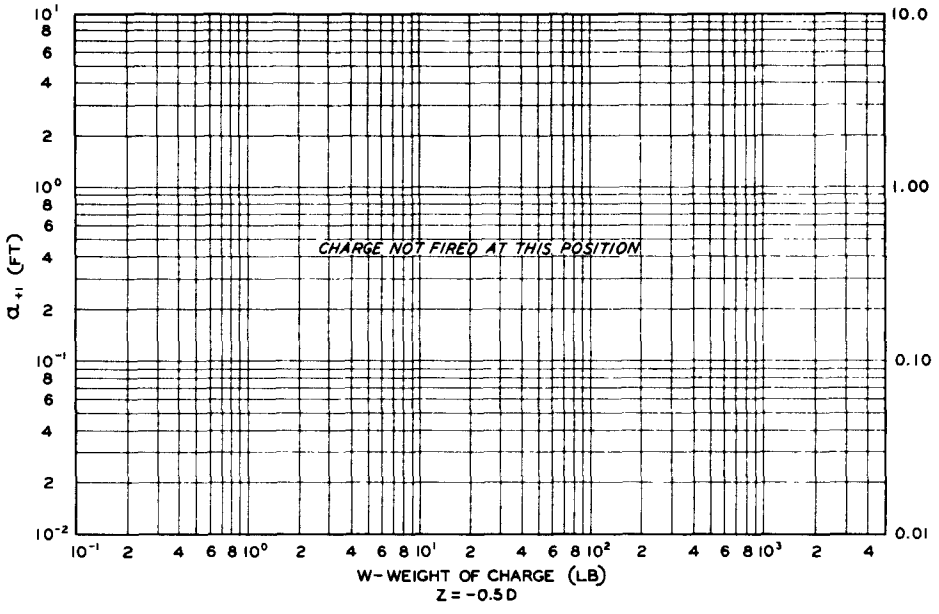


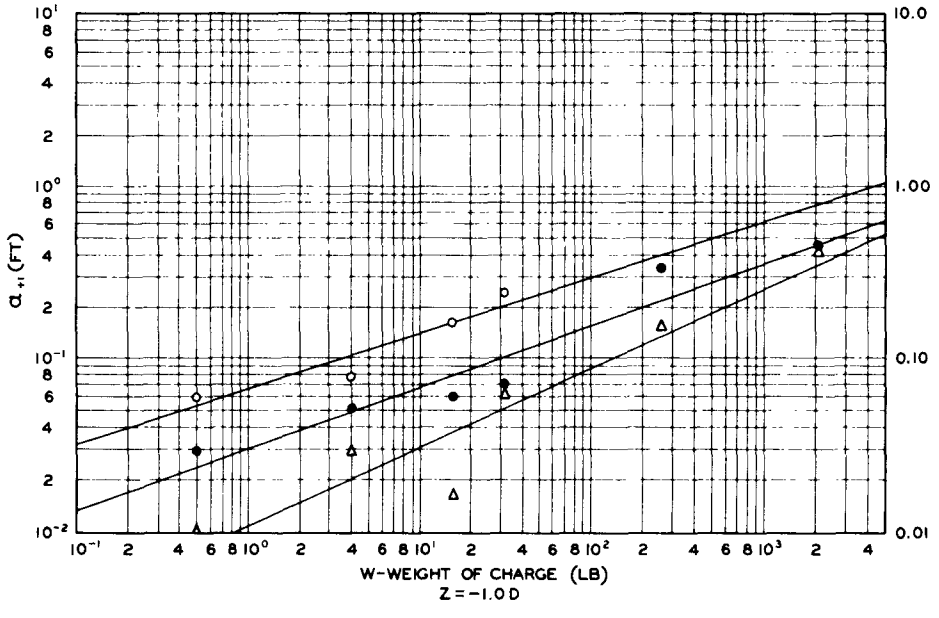
- ○ $R/D = 60$
- ● $R/D = 100$
- △ $R/D = 200$
- a_{+1} HEIGHT OF CREST ABOVE STILL WATER IN FEET
- D DEPTH OF WATER IN FEET
- Z CHARGE POSITION

EFFECT OF CHARGE WEIGHT ON WAVE HEIGHT

FIRST CREST

$D/W^{\frac{1}{3}} = 0.088$





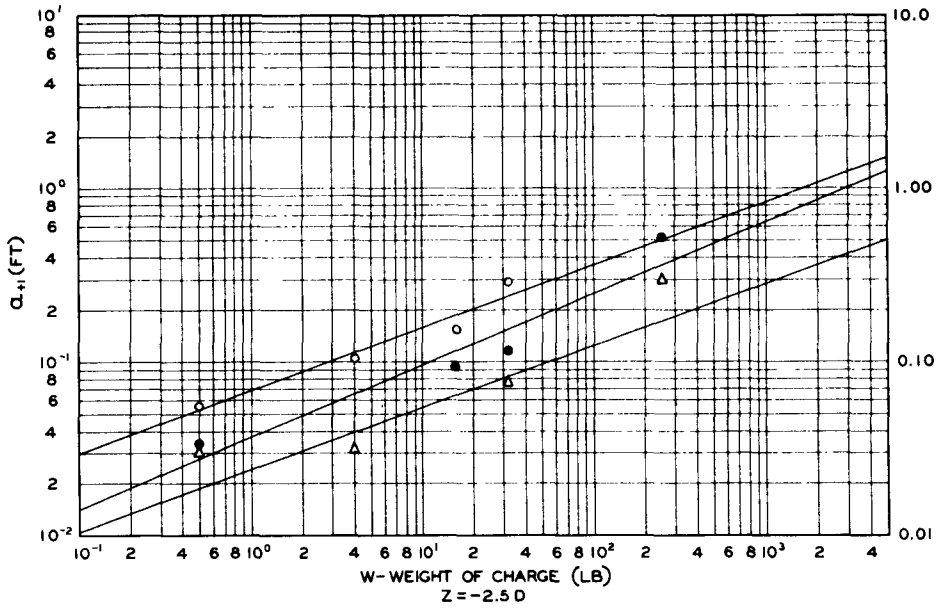
- ○ $R/D = 60$
- ● $R/D = 100$
- △ $R/D = 200$
- a_{+1} HEIGHT OF CREST ABOVE STILL WATER IN FEET
- D DEPTH OF WATER IN FEET
- Z CHARGE POSITION

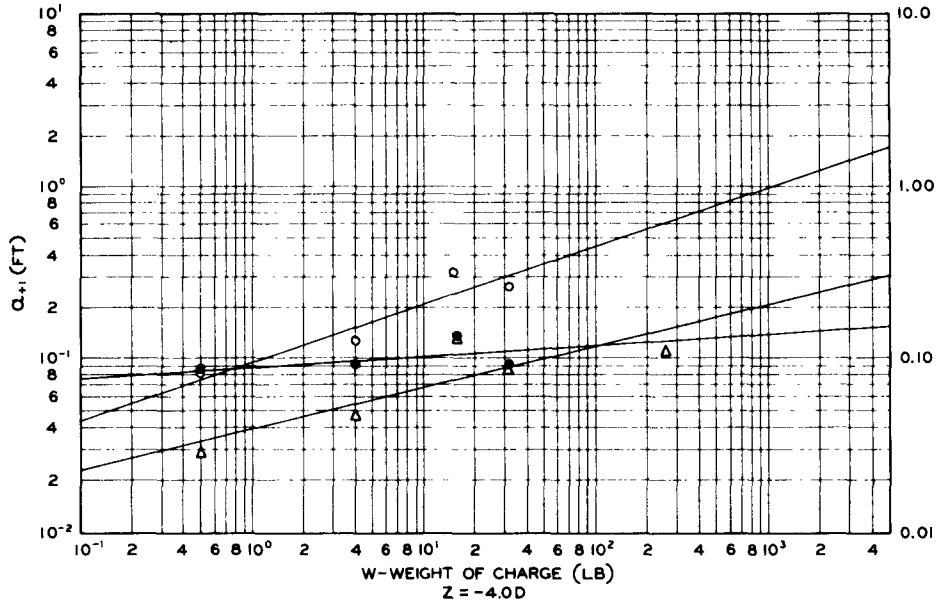
EFFECT OF CHARGE WEIGHT ON WAVE HEIGHT

FIRST CREST

$D/W^{\frac{1}{3}} = 0.088$

PLATE 48



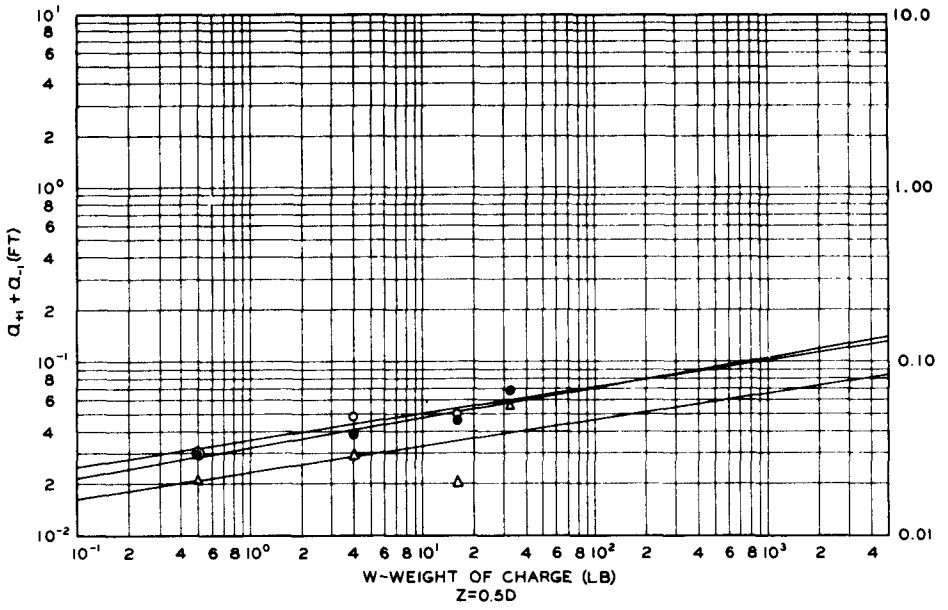


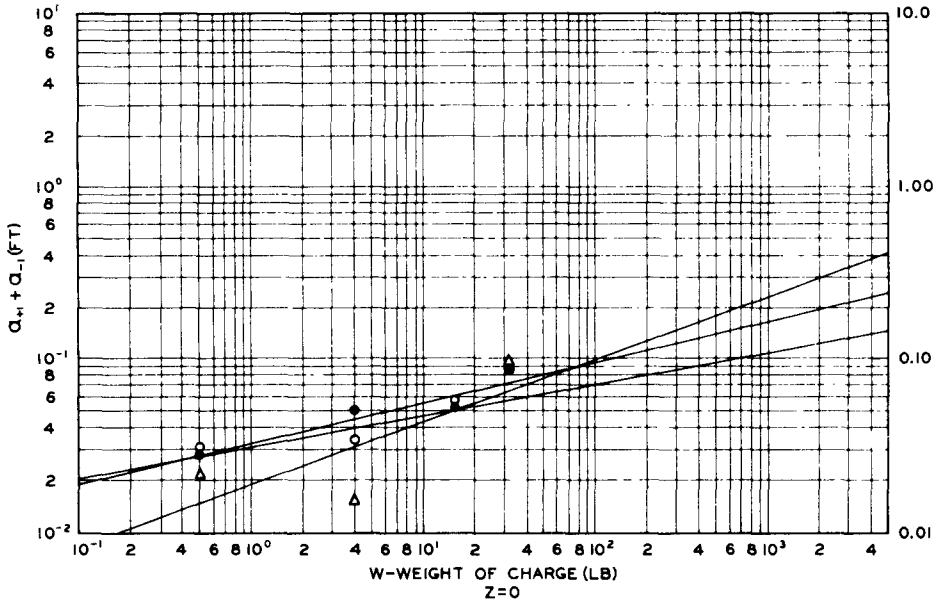
- ○ $R/D = 60$
- ● $R/D = 100$
- △ $R/D = 200$
- a_{+1} HEIGHT OF CREST ABOVE STILL WATER IN FEET
- D DEPTH OF WATER IN FEET
- Z CHARGE POSITION

EFFECT OF CHARGE WEIGHT ON WAVE HEIGHT

FIRST CREST

$D/W^{\frac{1}{3}} = 0.088$





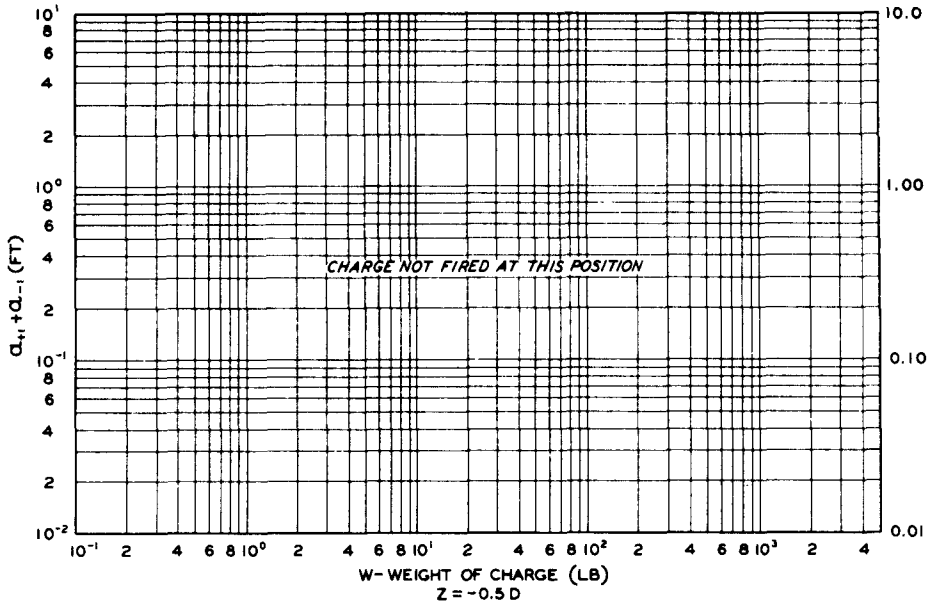
o	$R/D = 60$
●	$R/D = 100$
Δ	$R/D = 200$
a_{+1}	HEIGHT OF CREST ABOVE STILL WATER IN FEET
a_{-1}	DEPTH OF TROUGH BELOW STILL WATER IN FEET
$a_{+1} + a_{-1}$	HEIGHT OF WAVE-CREST TO TROUGH IN FEET
D	DEPTH OF WATER IN FEET
Z	CHARGE POSITION

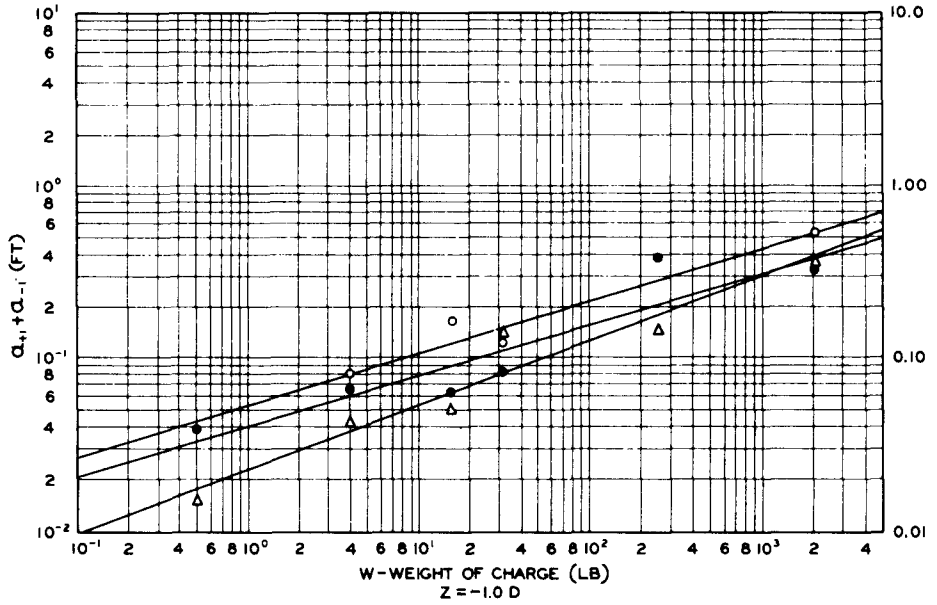
EFFECT OF CHARGE WEIGHT ON WAVE HEIGHT

FIRST CREST PLUS FIRST TROUGH

$D/W^{\frac{1}{3}} = 0.088$

PLATE 50



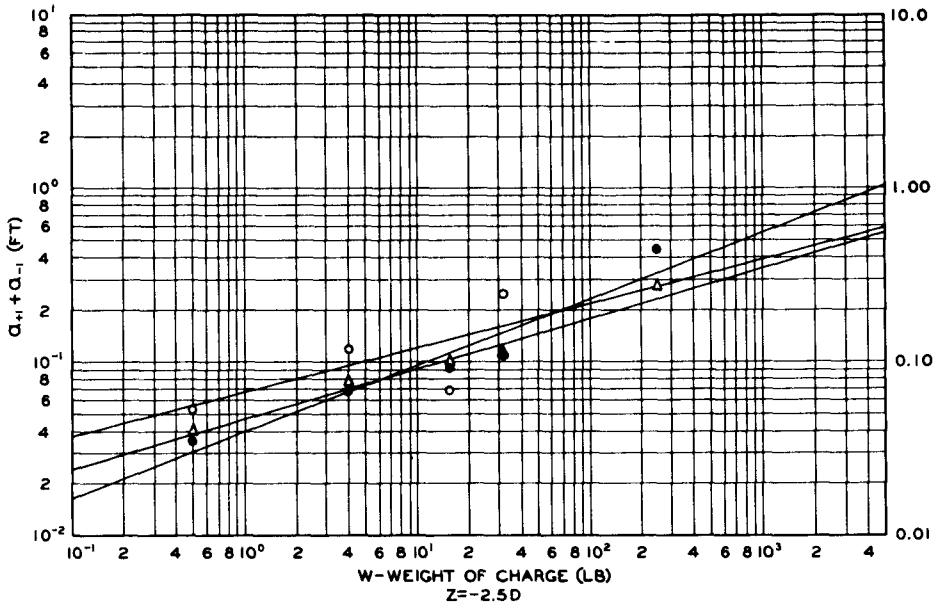


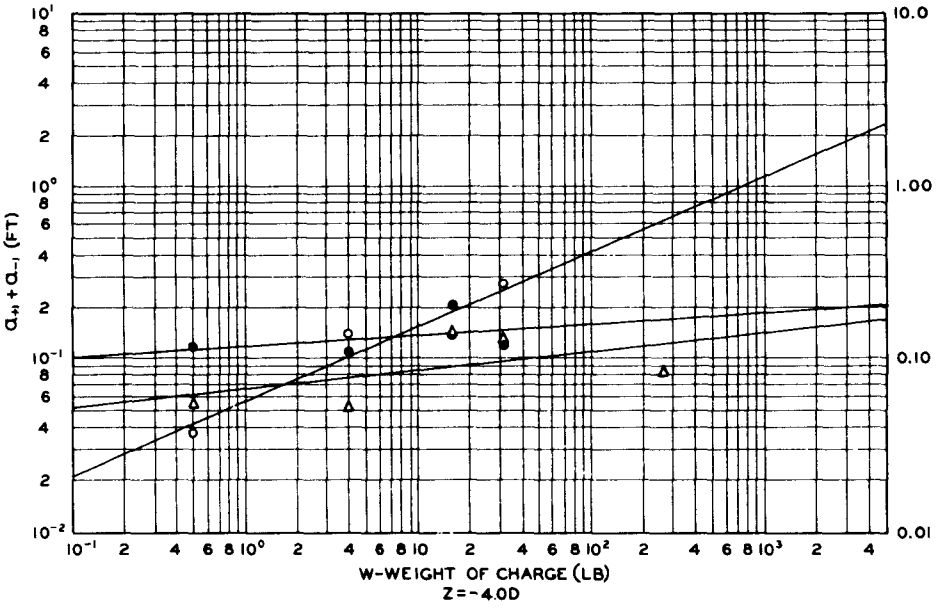
o	$R/D = 60$
●	$R/D = 100$
Δ	$R/D = 200$
a_{+1}	HEIGHT OF CREST ABOVE STILL WATER IN FEET
a_{-1}	DEPTH OF TROUGH BELOW STILL WATER IN FEET
$a_{+1}+a_{-1}$	HEIGHT OF WAVE-CREST TO TROUGH IN FEET
D	DEPTH OF WATER IN FEET
Z	CHARGE POSITION

EFFECT OF CHARGE WEIGHT ON WAVE HEIGHT

FIRST CREST PLUS FIRST TROUGH

$D/W^{\frac{1}{3}} = 0.088$





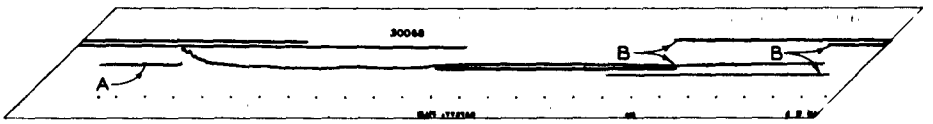
o	$R/D = 60$
●	$R/D = 100$
Δ	$R/D = 200$
a_{+1}	HEIGHT OF CREST ABOVE STILL WATER IN FEET
a_{-1}	DEPTH OF TROUGH BELOW STILL WATER IN FEET
$a_{+1}+a_{-1}$	HEIGHT OF WAVE-CREST TO TROUGH IN FEET
D	DEPTH OF WATER IN FEET
Z	CHARGE POSITION

EFFECT OF CHARGE WEIGHT ON WAVE HEIGHT

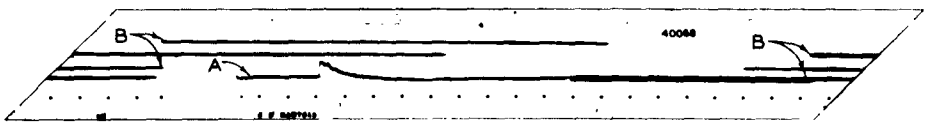
FIRST CREST PLUS FIRST TROUGH

$D/W^{\frac{1}{3}} = 0.088$

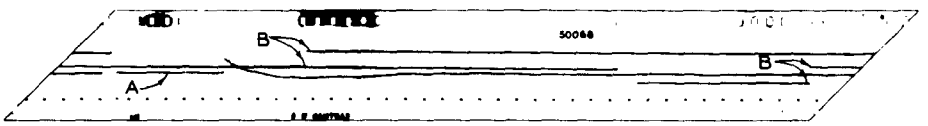
PLATE 52



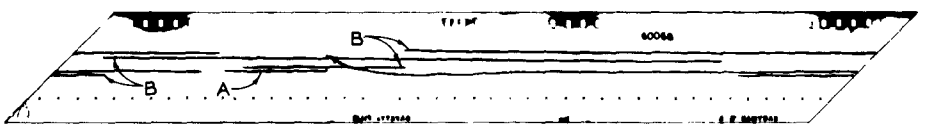
R = 15.12FT λ = 6



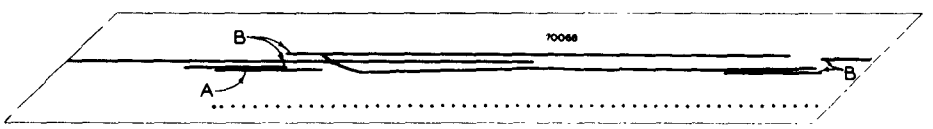
R = 15.12FT λ = 6



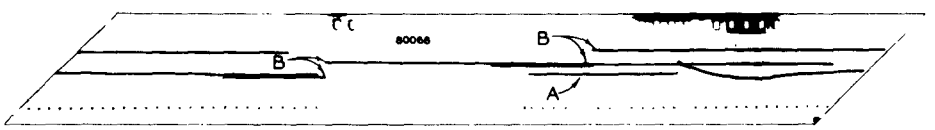
R = 25.20FT λ = 10



R = 25.20FT λ = 10



R = 37.80FT λ = 15



R = 50.40FT λ = 20

CHARGE WEIGHT – 16LB
WATER DEPTH – 0.22FT
CHARGE POSITION – Z = -10D
R – DISTANCE FROM CHARGE IN FT.
λ – REDUCED DISTANCE FROM CHARGE ($R/W^{\frac{1}{3}}$)
A – PRESSURE–TIME TRACE
B – CALIBRATION STEPS

TYPICAL AIR-BLAST RECORDS
BOTTOM MATERIAL–SAND
$D/W^{\frac{1}{3}} = 0.088$

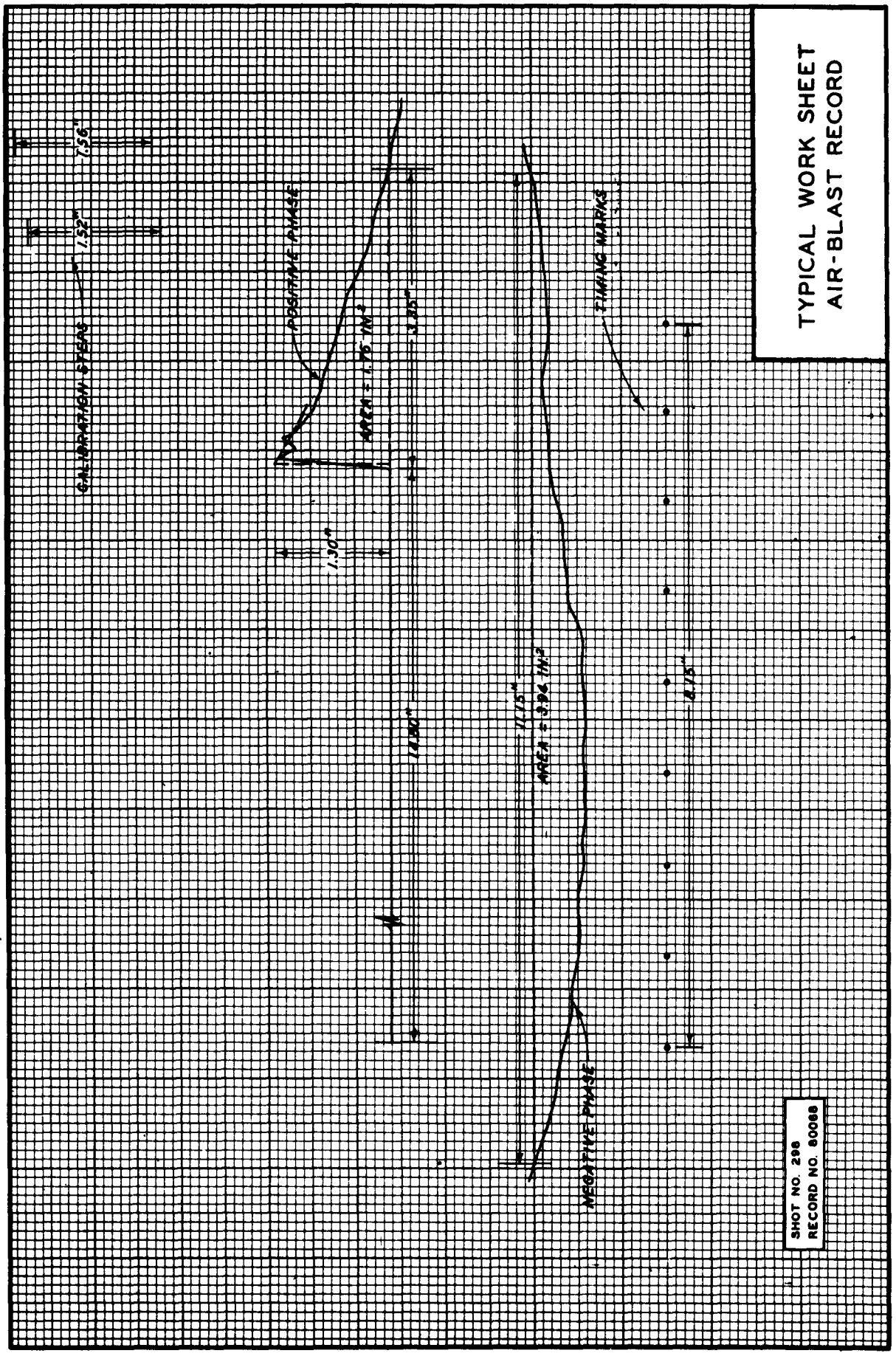
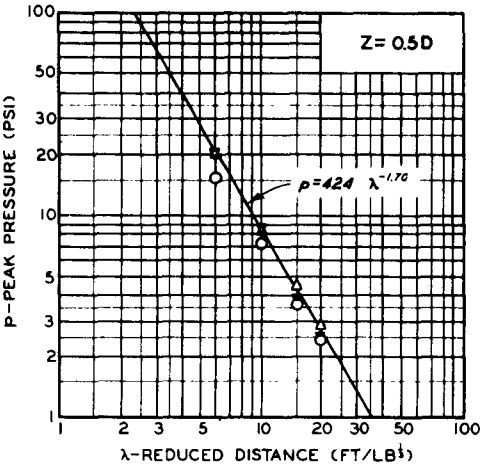
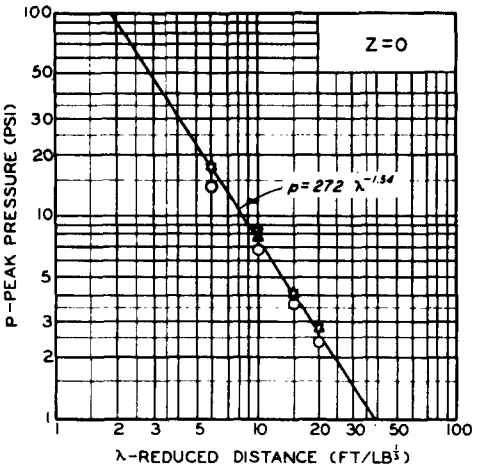
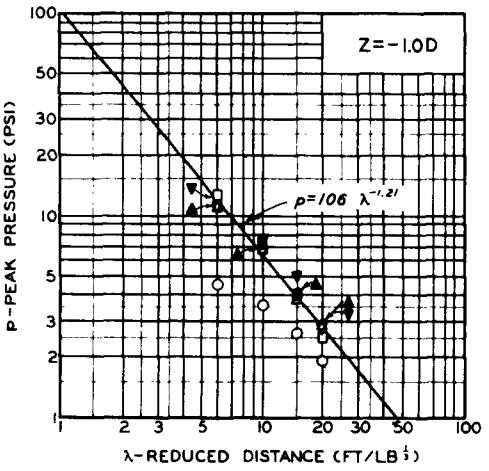
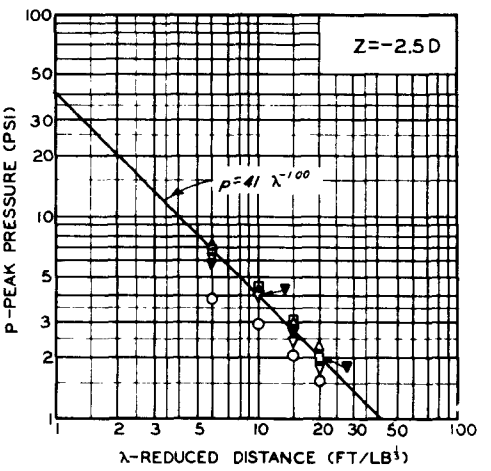

TYPICAL WORK SHEET
AIR-BLAST RECORD
.56"
1.52"
CALIBRATION STEPS
POSITIVE PHASE
AREA = 1.76 IN.²
1.35"
1.30"
14.80"
TIMING MARKS
11.15"
AREA = 3.94 IN.²
2.15"
NEGATIVE PHASE
SHOT NO. 298
RECORD NO. 80068

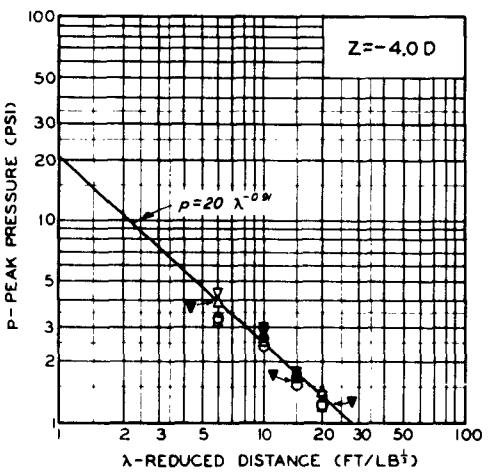
PLATE 54







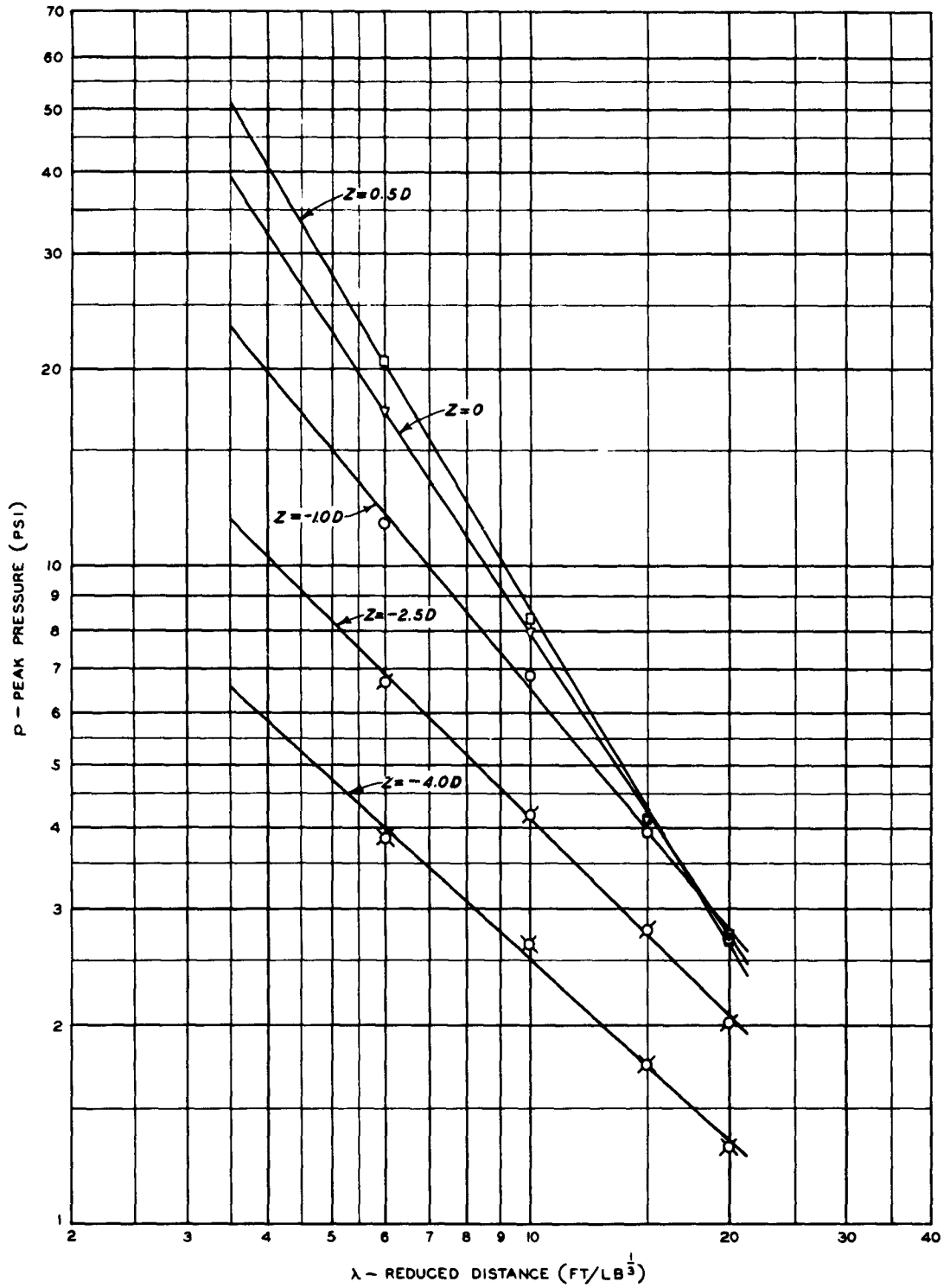




○ 0.5 LB CHARGES
△ 4 LB CHARGES
▽ 16 LB CHARGES
□ 32 LB CHARGES
▼ 256 LB CHARGES
▲ 2048 LB CHARGE

VARIATION OF AIR-BLAST PEAK PRESSURE WITH REDUCED DISTANCE FOR VARIOUS CHARGE POSITIONS

BOTTOM MATERIAL - SAND
$D/W^{\frac{1}{3}} = 0.088$



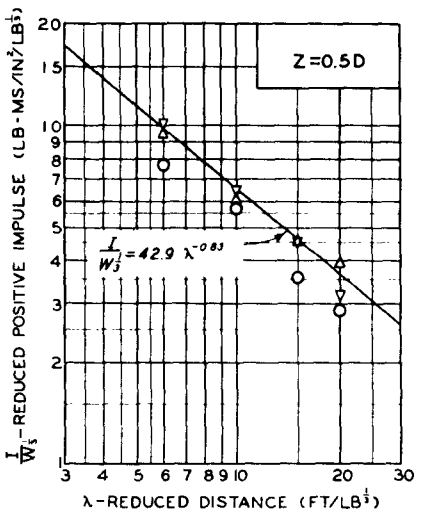
□ CHARGE ABOVE SURFACE (Z=0.5D)
▽ CHARGE AT SURFACE (Z=0)
○ CHARGE AT BOTTOM (Z=-1.0D)
⌀ CHARGE BELOW BOTTOM (Z=-2.5D)
⌘ CHARGE BELOW BOTTOM (Z=-4.0D)

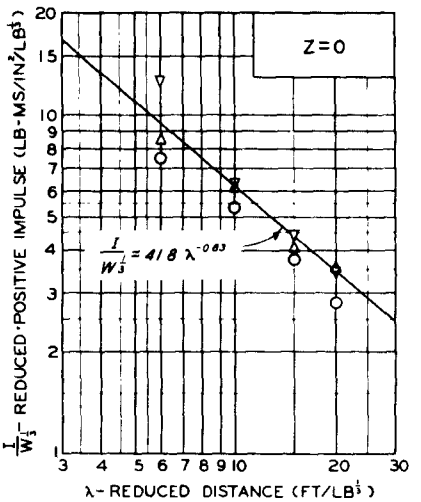
VARIATION OF AIR-BLAST PEAK PRESSURE WITH REDUCED DISTANCE

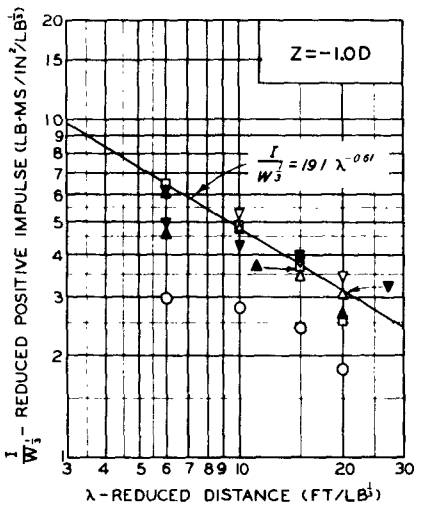
BOTTOM MATERIAL - SAND

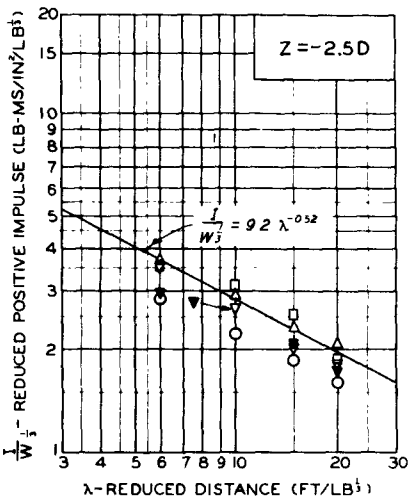
$D/W^{\frac{1}{3}} = 0.088$

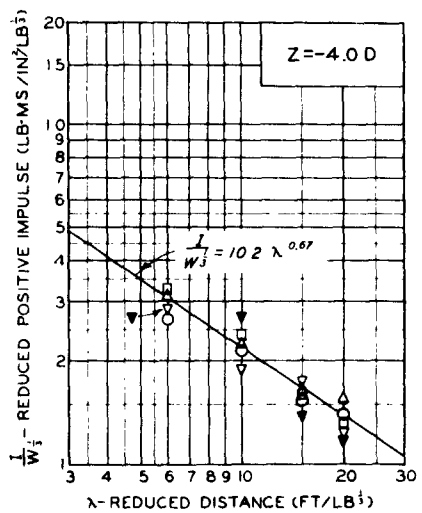
PLATE 56









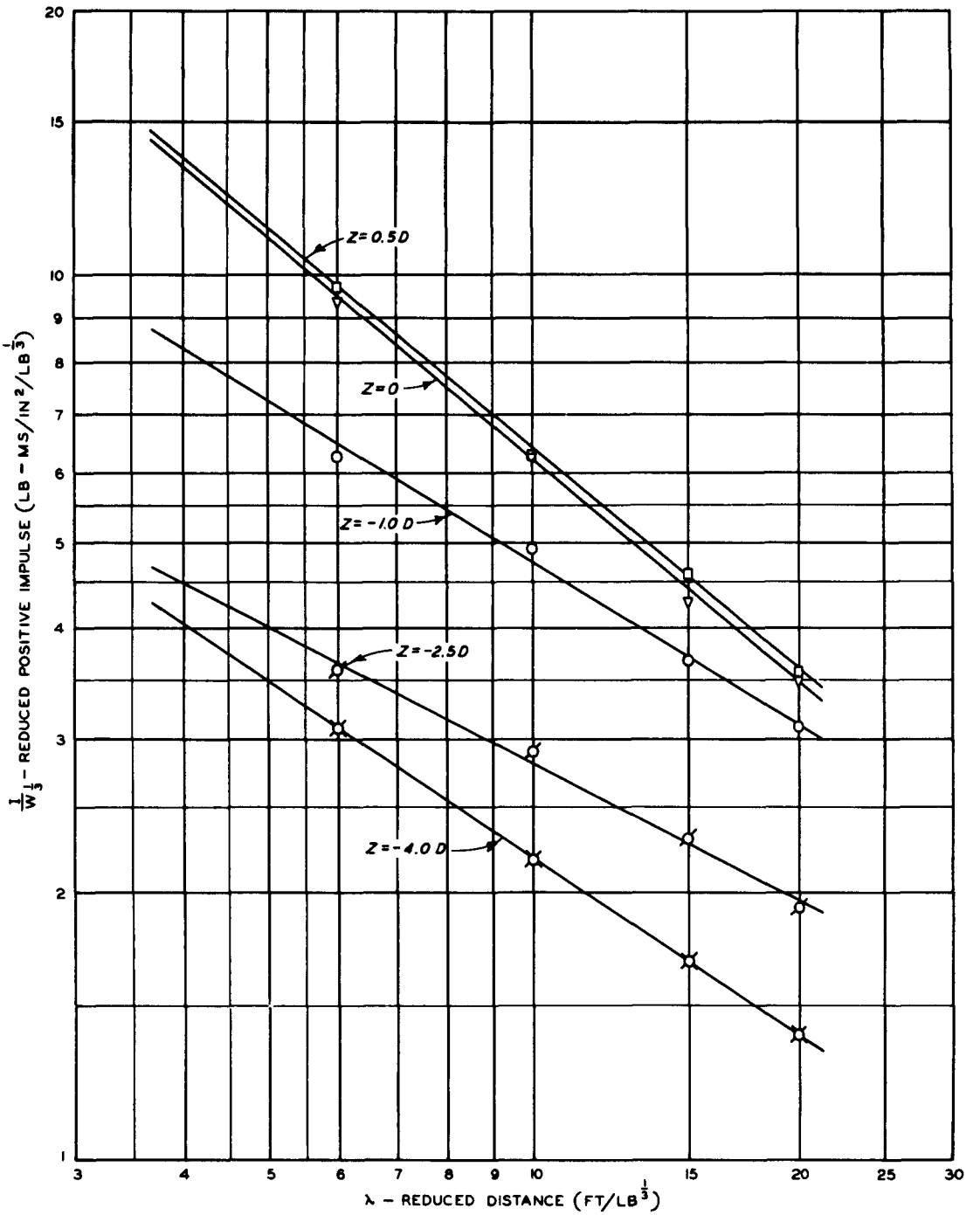


- ○ 0.5 LB CHARGES
- △ 4 LB CHARGES
- ▽ 16 LB CHARGES
- □ 32 LB CHARGES
- ▼ 256 LB CHARGES
- ▲ 2048 LB CHARGE

VARIATION OF REDUCED AIR-BLAST POSITIVE IMPULSE WITH REDUCED DISTANCE FOR VARIOUS CHARGE POSITIONS

BOTTOM MATERIAL - SAND

$D/W^{\frac{1}{3}} = 0.088$



□ CHARGE ABOVE SURFACE (Z=0.5D)
▽ CHARGE AT SURFACE (Z=0)
○ CHARGE AT BOTTOM (Z=-1.0D)
⊘ CHARGE BELOW BOTTOM (Z=-2.5D)
⊠ CHARGE BELOW BOTTOM (Z=-4.0D)

VARIATION OF REDUCED AIR-BLAST POSITIVE IMPULSE WITH REDUCED DISTANCE

BOTTOM MATERIAL - SAND

$D/W^{\frac{1}{3}} = 0.088$

PLATE 58

APPENDIX

SAMPLE CALCULATIONS OF AN AIR-BLAST RECORD

1. To illustrate the methods used in the computation of air-blast data, a sample calculation of record number 80068, plate 53, is presented.

2. The first step was to enlarge the film strip and make a tracing of the items of interest. This tracing is shown on plate 54 and includes the positive phase of the pressure-time trace, the negative phase of the pressure-time trace, the length of the time of arrival line, the calibration steps, and a definite time interval consisting of several time dots.

3. Information obtained from the instrumentation data sheet was as follows:

Shunt capacitance (C_s) = 5.00 mμ farads

Gage factor (KA value) = 87.7 μμ coulombs

Calibration voltage (E_c) = 60.01 m-volts

4. The average calibration declination, d_c, determined by averaging the two calibration steps, was combined with the instrumentation data to obtain the calibration factor, F, in the formula

$$F = \frac{C_s E_c}{d_c KA} = \frac{300.05}{135.06} = 2.222$$

5. The peak pressure displacement (d_p) was obtained by extending the pressure decay line of the pressure-time trace to a point vertically above the mid-point of the pressure rise line. The displacement was multiplied by the calibration factor, F, to determine the peak pressure (p).

$$p = d_p F = 1.30 \times 2.222 = 2.89 \text{ psi}$$

6. The horizontal, or time, scale was determined by dividing the duration of the traced time interval by its length.

$$\frac{8 \text{ spaces} \times 2.5 \text{ ms/space}}{8.15 \text{ inches}} = 2.45 \text{ ms/in.}$$

7. The vertical, or pressure, scale was determined by dividing the computed peak pressure by the maximum displacement.

$$\frac{2.89 \text{ psi}}{1.30 \text{ in.}} = 2.22 \text{ psi/in.}$$

8. The area, or impulse, scale was determined by multiplying the time scale by the pressure scale.

$$2.45 \text{ ms/in.} \times 2.22 \text{ psi/in.} = 5.44 \text{ ms-psi/in.}^2$$

9. The positive and negative impulses were computed by planimetering the area between the pressure-time curve and the base line and multiplying by the area scale.

Positive Impulse = $1.76 \text{ in.}^2 \times 5.44 \text{ ms-psi/in.}^2 = 9.57$ psi-ms

Negative Impulse = $3.94 \text{ in.}^2 \times 5.44 \text{ ms-psi/in.}^2 = 21.43$ psi-ms

10. The positive duration, negative duration, and time of arrival were obtained by applying the time scale to their respective distances.

Positive Duration = 3.35 in. x 2.45 ms/in. = 8.21 ms

Negative Duration = 11.15 in. x 2.45 ms/in. = 27.32 ms

Time of Arrival = 14.80 in. x 2.45 ms/in. = 36.26 ms

11. The average charge-to-gage velocity was computed by dividing the radial distance from the charge to the gage by the time of arrival for the gage.

$$\frac{50.40 \text{ ft}}{36.26 \text{ ms}} = 1.390 \text{ ft/ms} = 1390 \text{ ft/sec}$$

12. The average between gages, or gage-to-gage velocity, was computed by dividing the distance between the gages by the difference in times of arrival.

$$\frac{50.40 \text{ ft} - 37.80 \text{ ft}}{36.26 \text{ ms} - 25.37 \text{ ms}} = 1.157 \text{ ft/ms} = 1157 \text{ ft/sec}$$